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HEALTH PHYSICS ASPECTS OF DEPLETED URANIUM

MARCH [illegible]

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DRDME-VR

18 December 1981

SUBJECT: Setting Control Boundaries from Igloos Storing Pyrophoric Deptleted Uranium (DU)

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1. Inclosed is the report "Setting Control Boundaries from Igloos Storing Pyrophoric Depleted Uranium." This document details the physical, environmental, and regulatory grounds limiting exposure to toxic, airborne aerosols of Uranium-238 in the event of unplanned ignition and fire of associated munitions.

2. Point of contact for additional information is Michael Funkhouser, Autovon 354-5437 or Robert C. McMillan, Autovon 354-5133, this Command.

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SETTING CONTROL BOUNDARIES FROM IGLOOS STORING PYROPHORIC DEPLETED URANIUM (DU)

1. PURPOSE:

a. A set of control boundaries are provided in this report and extend from stockpiles of munitions incorporating depleted uranium (DU) whether in storage or in transit. These boundaries minimize potential exposure to toxic, airborne aerosols of pyrophoric uranium.

b. These control boundaries represent a characteristic measurement of dose from an inhaled aerosol of uranium generated by an unplanned ignition of associated munitions. This measurement is a complex calculation. Viable regulatory limits must be assessed for a single acute emergency release of a radio-chemical agent. Significant population differences will mitigate toxic exposures to this agent. Physical characteristics of the agent, on-site storage configuration of associated munitions, and local micro-meteorological conditions will necessarily impact on the final dose commitment to any one individual at the control boundary.

2. REGULATORY LIMITS AND RADIOLOGICAL MODELS.

a. Current regulatory requirements limiting exposure to concentrations of airborne aerosols of uranium are derived from extensive research and industrial epidemiology. The Nuclear Regulatory Commission (NRC) has promulgated Table I, Appendix B, at 10 CFR 20 which limits weekly occupational exposure to aerosols of Uranium-238 (DU) at 0.2 mg/m^3 for a time integrated concentration (CT) factor of 8 $mg \cdot hr/m^3$.

b. Similarly the American Conference of Governmental Industrial Hygienists (ACGIH) has recommended a Threshold Limit Value of 0.25 mg/m^3 at references 1 and 2 (at paragraph 9) for airborne concentrations of uranium and its aerosols.

c. A significant proposal by I.S. Eve at reference 3, incl 1, suggests a maximum planned emergency inhalation for occupationally exposed persons to 10 mg of uranium. At a breathing rate of 1.25 m^3/hr, a maximum planned emergency CT factor of 8 $mg \cdot hr/m^3$ or 480 $mg \cdot min/m^3$ is calculated.

d. This value is consistent with both the Reference Man Model and the Task Group Lung Model as calculated by McMillan and Air Force at references 4 and 5. Although these models assess radiological toxicity, chemical toxicity to the kidneys following acute inhalation of somatic transportable DU at references 6 and 7 cannot be dismissed. Hence, a CT factor of 480 $mg \cdot min/m^3$ is not only conservative with respect to the radiological models as reported; it is also consistent with laboratory studies at references 1, 2, 7, 8, 9, 10 and 11 assessing nephrotoxicity following acute inhalation and ingestion of both soluble and insoluble uranium compounds in excess of 480 $mg \cdot min/m^3$.

3. PHYSICAL AND CHEMICAL PROPERTIES.

a. Uranium is a dense metallic white metal which is pyrophoric when finely divided. It oxidizes in air and dissolves in acidic solution. Natural uranium consists of three isotopes: U-234, U-235, and U-238. (The latter most is principally depleted uranium). Each is radioactive and chemically toxic. With a chemical valence of 3, 4, 5, or 6, uranium forms complex molecular salts, nitrates, oxides, and carbonates. Each form is relatively soluble depending on the pattern of physical entry into the body and its metallurgical state.

b. Solubility is greatly enhanced when uranium compounds are dissolved in carbonic solutions in finely divided grains. Once dissolved in extracellular fluids, a mildly acidic solution, uranium becomes a nephrotoxic agent to the kidneys an insoluble aerosols become a radiotoxic agent to the lungs. In particular, the soluble characteristics of aerosols of complex uranium oxides (UxOy) is discussed at reference 6. Up to 50% of aerosolized DU dissolves in simulated lung fluid (a carbonic solution) in seven days. This fraction represents a transportable nephrotoxic dose of uranium to the kidneys. About 80% of this fraction is released to the urine in 24 hours at references 9 and 12. The remaining 20% is released from the kidneys with a biological half life of 15 days at reference 13. The non-transportable fraction of 50% represents a radiological dose commitment to the lungs with a biological half life of 380 days at reference 12. An evaluation of dose commitment follows at paragraph 8.

4. POPULATION CHARACTERISTICS AND DOSE RESPONSE.

a. An unplanned, spontaneous ignition of munitions incorporating quantities of DU in storage or transit may expose local populations including support personnel, to potentially toxic levels of airborne aerosols of uranium. Pertinent radiological limits, however, have been modelled on the concept of a radiation worker whose slightly elevated body burden of uranium is held constant by the particular retention and excretion dynamics which are characteristic of an adult (Reference Man ICRP 23). Such modelling is absent among a diverse population of infants, children, and adults of various consitutions with no significant body burden of uranium. The nephrotoxic limit of 3μgm/gm of kidney at references 2 and 5 is, however, uniformly applied throughout the population.

b. Unlike radiological limits which assume a linear response as dose approaches zero at reference 14, the nephrotoxic limit is a threshold effect characteristic of repairable, incipient kidney damage at reference 2 and 9. The maximum permissible occupational exposure from an actue, emergency release of airborne aerosols of uranium is, therefore, assumed applicable to a local population, not subject to chromic weekly exposures permitted among adult radiation workers.

c. The proposed control boundaries derived at paragraph 7 are consistent with NRC requirements and ACGIC recommendations limiting exposure to airborne aerosols of uranium. These boundaries are especially sensitive to on-site configuration and

storage parameters. Furthermore, the rate of oxidation, pyrotechnics, composition and design of the munitions, local meteorological conditions and effective emergency response to an unplanned incident will greatly mitigate upon any potential exposure. Relevant onsite and meteorological assumptions are proposed at paragraph 6.

5. ONSITE CONFIGURATION AND ASSUMPTIONS.

a. To assess the nephrotoxic fraction of somatic transportable (soluble) DU released to the plume during a fire, the following assumptions are consistent with references 6, 15 and 16:

(1) 30% of the rounds are "effected"; 70% are "uneffected."

(2) 50% of the rounds are aerosolized; 50% are deposited onsite.

(3) 50% of the aerosolized compounds are of respirable size; 50% are nonrespirable.

(4) 50% of the aerosolized compounds of respirable size are transportable (nephrotoxic limits); 50% are nontransportable (radiotoxic limit).

b. The somatic transportable nephrotoxic contribution to the kidneys is 3.75%. This fraction is the product of the effected, aerosolized, respirable and soluble fractions from compounds of uranium released to the plume following spontaneous ignition and fire of stored GAU-8 ammunition.

c. The somatic nontransportable radiotoxic contribution to the lungs is likewise 3.75%. This fraction is the product of the effected, aerosolized, respirable and insoluble fractions from compounds of uranium released to the plume.

6. MICRO-METEOROLOGY AND BOUNDARY LIMITS.

a. Aerosols of uranium are essentially trapped and carried by a plume whose displacement and configuration is characterized by the adiabatic lapse rate, atmospheric diffusion, radiant index, turbulence, and wind velocity. Such effects are subsumed in Pasquill's Stability Categories A, B, C, D, E, and F. Categories A, B, C, and D characterize normal daylight adiabatic lapse rates. A wind velocity of 1 m/sec (2.2 mi/hr) suggests an extremely unstable lapse rate designated A; at 3 m/sec, a moderately unstable rate of B; and at 5 m/sec or more, a slightly unstable or neutral rate of C or D.

b. Seasonal variations tend toward the unstable lapse rates during summer (A or B) and near neutral during winter (C or D).

c. Categories D, E, and F characterize nightime inversions. Light winds of less than 3 m/sec favor the moderately stable category of F, while winds greater than 3 m/sec favor the slightly stable category of D. Little seasonal variation is noted. Detailed theoretical and empirical studies can be found at references 17, 18 and 19 which can be adapted to local conditions.

d. In the absence of meteorological data, a daylight stability category of A may be considered for near calm. Categories B or C for perceptible breezy or windy conditions. At night, consider category F for near calm; otherwise, consider categories E or D for perceptible breezy or windy conditions.

e. In general, decreasing wind velocity will transport a plume with a given airborne concentration of aerosols an increased distance downwind through a narrowly defined sector of about 22.5 degrees. Similarly, a calm nighttime inversion will transport an airborne aerosol concentration an increased distance.

f. Practical control boundaries, therefore, may not assure an optimum limiting exposure to extremes in local meteorological conditions. However, the combination of numerous safety variables and probabilities of spontaneous ignition suggest the recommended control boundaries are practicable.

7. DERIVED CONTROL BOUNDARY LIMITS.

a. The derived control boundaries increase in inverse proportion to the integrated, time-concentration factor designated as D in units of mg·min/m^3. The boundaries furthermore increase in direct proportion to the source strength. The source strength is the product of the amount of stored uranium in units of kilograms per unit wind velocity (kg·sec/m) and the fraction of transportable uranium (3.75%) released to the atmosphere following spontaneous ignition and fire of stored ammunition.

b. To enclose a given exposure (D) in mg·min/m^3, the derived control boundaries must gradually increase as the vertical atmospheric temperature gradient proceeds from an extremely unstable lapse rate to an extremely stable lapse rate (A through F). Graphs from Figures 4.3.1a. and b. through 4.3.6 a. and b. at reference 20 provide recommended boundaries for each of Pasquill's Atmospheric Stability Categories

c. Recommended control boundaries are provided at inclosure 2. These boundaries minimize potential exposure to nephrotoxic and radiotoxic aerosols of uranium during a fire for each stability class A through F.

d. Initial conditions which minimize toxic exposures follow from recommended CT factor as developed at paragraph 2. Higher exposures result as control boundaries are reduced. Similarly, higher exposures result as the product of the source strength and the fraction of transportable uranium released from a fire increases. Higher wind velocity effectively reduces the source strength on account of increased atmospheric mixing with a longer volume of air.

e. To set initial control boundaries upon ignition and fire of GAU-8 munitions, use the nomograph at inclosure 3 and make the following assessment:

(1) Determine the mass (kg) of depleted uranium at storage site which is in conflagration.

(2) Determine the wind speed, direction, and atmospheric stability class from onsite instrumentation.

(a) Judge atmospheric stability class from outline at paragraph 6; otherwise assume stability class F.

(b) Read wind conditions from appropriate instruments: otherwise assume wind speed of one (1) meter per second (m/s).

(3) Divide the amount (A) of burning mass of depleted uranium by the wind speed (U) to obtain (A/U) in units of (kg·sec/m).

(4) Use the nomograph and connect the value of (A/U) to either side of the graph and read the initial control boundary in meters for a specific atmospheric class.

f. The graphs from Figures 4.3.1a. and b. through 4.3.6a. and b. at reference 20 may be directly utilized by making the following adjustments in nomenclature:

(1) Replace D in figures with (CT) at paragraph 2.

(2) Replace Q(mg) in figures with A(mg)·f (Amount stored·somatic (non)transportable fraction from fire and deposited to the (lung)kidney) at paragraphs 5 and 7.

(3) Replace DU/Q in figures with (CT)·U/A·f = (CT)/(SS) where the source strength (SS) is (A·f/U) and U is the wind speed in meters per second (m/s).

(4) The quantity (CT)/(SS) decreases as a function of the reciprocal of the the distance in meters (m).

8. RADIOLOGICAL IMPLICATIONS AND POPULATION DOSE.

a. The dose commitment to the lungs is proportional to the infinite time integral of absorbed activity (μCi) from T = 0, following a single, acute inhalation of somatic nontransportable aerosols of uranium. This calculation assumes insignificant previous accumulation and no additional accumulation is assumed.

b. The activity (A) present in the lungs decreases at an exponental rate with time, or

$$A(t) = A_o e^{-\lambda_\varepsilon T}$$

where A_o is the inhaled activity deposited to the lungs from somatic nontransportable uranium, by the relation

$$A_o(\mu Ci) = CT\left(\frac{mg\cdot hr}{m^3}\right) \times V\left(\frac{m^3}{hr}\right) \times SpA\left(\frac{uCi}{mg}\right) \times f_i$$

where CT is the integrated time-concentration factor as developed at paragraph 2,

V is the ventilation rate of $1.25m^3/hr$ ref.(ICRP),

SpA is the specific activity for Uranium-238 of $0.333\ \mu Ci/10^3 mg$ of DU,

f_i is the insoluble, nontransportable, fraction deposited in the lungs as developed in paragraph 5,

and

λ_ε is the effective elimination rate of ln2/380 days (ref. 12).

Upon substitution and evaluation of the numerical constants, the inhaled deposition is

$$A_o = 8.0\ \frac{mg.hr}{m^3} \times \frac{1.25m^3}{hr} \times \frac{0.333uCi}{10^3 mg} \times 0.0375$$

$$A_o = 1.25 \times 10^{-4} uCi$$

c. The dose equivalent (DE) rate to the lungs in units of mrem/day follows the differential relation

$$\frac{d}{dt} DE\left(\frac{mrem}{day}\right) = A_o e^{-\lambda_\varepsilon T} (\mu Ci) \times \mathcal{E}\left(\frac{MeV \cdot rem}{dis \cdot rad}\right) \times \frac{1}{m(gm)} \times$$
$$\left[\frac{10^3 mrem}{rem} \times 1.6 \times \frac{10^6 erg}{MeV} \times \frac{gm \cdot rad}{100 erg} \times \frac{86400\ sec}{day} \times 37 \times 10^3\ \frac{dis}{sec \cdot \mu Ci}\right]$$

where

$\mathcal{E}$ is the effective absorbed energy per disintegration of 43 MeV·rem/dis·rad for Uranium-238 (DU)

and

m is the mass of the lungs of 1000 gm. Upon substitution and evaluation of the numerical constants of proportionality in brackets, the dose equivalent rate to the lungs becomes

$$\frac{d}{dt} DE\left(\frac{mrem}{day}\right) = 2.2 \times 10^3 A_o e^{-\lambda_\varepsilon T}$$

d. Solution to the infinite time integral of absorbed activity from t = o becomes the dose commitment to the lungs or

$$DE(mrem) = \frac{2.2 \times 10^3 A_o}{\lambda_E} (1-e^{-\lambda_E T})$$

where

$$A_o = 1.25 \times 10^{-4} uCi$$

$$\lambda_E = \ln 2/380 = 1.82 \times 10^{-3} \text{ day}^{-1}$$

(1) In one year the dose commitment to the lungs is:

$$\underset{1yr}{DE(mrem)} = \frac{2.2 \times 10^3 \quad (1.25 \times 10^{-4} uCi)}{1.82 \times 10^{-3}} \cdot day \cdot (1-\exp(-1.82 \times 10^{-3} \times 365)) \frac{(mrem)}{uCi.day}$$

$$= 73.3 \text{ mrem}$$

(2) In 50 yrears the dose commitment to the lungs is

$$\underset{50yr}{DE(mrem)} = 2.2 \times 10^3 \frac{(1.25 \times 10^{-4})}{1.82 \times 10^{-3}}$$

$$= 151 \text{ mrem}$$

e. The derived annual dose commitment to the lungs following a single, acute inhalation of aerosols of uranium is less than 15% permitted nonoccupationally exposed individuals. If the assumptions at paragraph 5 are reliable, one may be tempted to augment the nontransportable fraction of activity deposited to the lungs as developed at paragraph 2 by enhancing the CT factor and reduce the derived control boundaries proportionately. A six fold increase in the CT factor from 8 to 48 $mg.hr/m^3$ results in an annual dose commitment to the lungs of 6 x 73.3 mrem or 440 mrem. Although less than the permitted annual nonoccupational dose, a six fold increase represents an acute insult of 10mg x 6 x 0.0375 or 2.25mg of somatic transportable (soluble) uranium to the kidneys. This exceeds the maximum permissible uranium limit to the adult size kidney which is 0.9mg; and it greatly exceeds the permissible uranium limit to the infant size kidney which is 0.165 at references 2 and 5.

f. If the assumptions at paragraph 2 are reliable, an increase in the somatic nontransportable radiotoxic contribution to the lungs from 3.75% to 22.5% at paragraph 5 would yield the same nephrotoxic and radiotoxic values of 2.25mg and 440 mrem respectively. Indeed an increase from 3.75% to 9% would match the adult limit: 10mg x 0.09 = 0.9mg. An acute insult of 10mg at a deposition fraction of 3.75% delivers 0.375mg to the kidney which is the child's nephrotoxic limit.

g. It is therefore the enhanced nephrotoxic sensitivity that governs the derived control boundaries at paragraph 7 while committing a nominal non-occupational radiological dose to an exposed population.

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SOME SUGGESTED MAXIMUM PERMISSIBLE SINGLE INTAKES OF URANIUM

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Abstract—The Recommendations of the International Commission on Radiological Protection (1959) give maximum permissible concentrations for uranium in air and water, but before the issue of *ICRP Publication* 6 in 1964, there were no instructions concerning the time over which MPC's based on chemical toxicity of uranium might be averaged. The present paper, which was circulated informally in the U.K. Atomic Energy Authority before the issue of *ICRP Publication* 6, makes some suggestions regarding [redacted] for instance:

(a) Maximum single intake of inhaled uranium in 1 day 2.5 mg

(b) Maximum single intake of ingested uranium in 1 day 150 mg

(c) Maximum planned emergency inhalation for occupationally-exposed persons 10 mg

The first two of these suggestions are now in line with the recommendations of *ICRP Publication* 6.

INTRODUCTION

THE 1959 *Report of ICRP Committee* II[1] stated that "over a period of 13 weeks, the [redacted] present in air or in water [redacted] during any 13-week period [redacted] by exposure at the constant levels indicated in subsection 1 above." *ICRP Main Commission Report* (1959)[1] indicated that doses averaged over 13 weeks should be measured in rems and therefore presumably this did not provide for [redacted] rather than to radioactivity. Paragraph 52 (f) of *ICRP Publication* 6[2] now lays down limits for the inhalation of not more than 2.5 mg of soluble uranium in 1 day, or the ingestion of not more than 150 mg of soluble uranium averaged over 2 days. The consequences of inhaling or ingesting a 13-week dose of uranium in a short period of time, before these limits were applied, are discussed below.

INHALED URANIUM

Radiation workers—inhaled soluble uranium

If a natural uranium airborne exposure at the maximum permissible level was averaged over 13 weeks the result would be as follows:

m.p.c.$_a$ U(nat) (soluble) $= 7 \times 10^{-11}\ \mu c/cm^3$ $= 210\ \mu g/m^3$ (40-hour week m.p.c.).

If this is integrated over 13 weeks or 65 working days, then exposure $= 210 \times 10 \times 65\ \mu g$ inhaled $= 136$ mg U inhaled in one incident ($10\ m^3$ air inhaled/day).

Twenty-five per cent of this goes to the blood stream, i.e. 34 mg (ICRP model).

Approximately 50 per cent of this would be excreted in less than 24 hr,[3] say in 1 l. of urine. Therefore urine would contain 17 mg/l. uranium (natural).

U.K. Atomic Energy Authority experience as quoted by BUTTERWORTH[4] shows that from a single exposure to uranium several mg/l. of uranium in urine would produce albuminuria, although prolonged exposures would produce albuminuria at lower levels of a few hundred μg/l. of uranium. One case of acute UF_6 inhalation seemed to produce albuminuria at 2 mg U/l. Therefore a figure of 17 mg/l. U(nat) in urine would almost certainly produce albuminuria, although whether this would be permanently harmful is a more debatable question. LUESSENHOP *et al.*[5] state that the minimal injected dose necessary to produce catalasuria and

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Incl 1

Table 1

Animal	Lethal dose* U(nat)	Equivalent in 60-kilo man
Rabbit	0.1 mg U/kg	6 mg
Guinea pig	0.3 mg U/kg	18 mg
Rat	1 mg U/kg	60 mg
Mouse	10–20 mg U/kg	600–1200 mg
Dog (subcutaneous "uranium nitrate")	about 2 mg U/kg	120 mg

* Expressed as lethal dose rather than LD_{50} since the dose-effect curve rises very steeply.

albuminuria in man is of the order of 0.1 mg uranium/kg body weight for hexavalent uranium. Thus for a 60-kilo man 6 mg in the body would be likely to [redacted]. This might be equivalent to an initial excretion of 3 mg uranium/l. urine.

Table 1 shows approximate [redacted] of uranyl nitrate hexa-hydrate solution administered [redacted] in five species of animals, and followed for up to 29 days.[4]

LUESSENHOP *et al.*[5] by extrapolation of experience gained from the Massachusetts Hospital series of cases consider that the injected lethal dose for man might be about [redacted] which is about the same level as for the rat. Therefore, [redacted]

From these sources of evidence 34 mg absorbed into the body in one incident would appear to be excessive. Therefore a 13-week dose all in one exposure must be ruled out on toxicity grounds. In man, the urinary excretion rate from a single dose of soluble uranium remains high for about 8 hr[3] and then starts to fall off fairly rapidly. It would seem reasonable therefore that 1 day's total exposure could be allowed as a single intake; this quantity is 2.1 mg in the air breathed (or to allow some free play 2.5 mg).

Radiation workers—inhaled insoluble uranium

For insoluble uranium the critical organ is considered to be the lung, based on radiation exposure rather than on toxic effect. Insoluble uranium in the lung is excreted very slowly through the kidneys;[7] therefore if it were certain that all the airborne uranium was insoluble, exposures should be able to be integrated over 13 weeks. However, it is difficult often to be sure that all the uranium is present in such form; moreover there might be considerable excretion in the urine even after 13 weeks had elapsed,[8] thus confusing the pattern of urine analysis during subsequent routine operations. Therefore, it might be wise not to make any exception of insoluble uranium unless in very well controlled circumstances. It may be worth noting that Patterson[8] describes two cases of human exposure to U_3O_8 in which urinary excretion after some days indicated a lung half-life of about 120 days, as postulated in the ICRP (1959) calculations for insoluble uranium.[1] Possibly the [redacted] of the uranium inhaled.

Population exposure—inhaled soluble uranium

It is suggested in paragraph 56 of ICRP (1959)[1] that, for exposure of special groups of the population, "the individual maximum permissible annual dose will not be exceeded from internal exposure of any single organ, if the release of radioactive material is planned on the basis of one-tenth of the maximum permissible concentration (MPC) in air or water as given for continuous occupational exposure (168-hour week)."

If it were allowable that integration of a uranium dose could take place over 1 year we have:

Occupational m.p.c.$_a$ U(nat) soluble (168-hr week) $= 3 \times 10^{-11}\ \mu c/cm^3$
$= 90\ \mu g/m^3$.

Therefore dividing by 10 for population exposure and integrating over 52 weeks, there would be produced in a single dose $\frac{90}{10} \times 20 \times 365\ \mu g = 66$ mg inhaled (assuming 20 m^3 of air inhaled per day), or 16 mg in the blood of an adult, with correspondingly less in a child. This again would be very likely to produce albuminuria, especially in those with damaged kidneys.

[redacted] but within limits, a [redacted]

and thus differs from the radiation hazard which, for many of its effects, is cumulative. Also HODGE *et al.*[9] in discussing MAC's for uranium in air, based their arguments on experiments in which animals were exposed to steady levels of atmospheric uranium rather than to a series of larger doses spaced at intervals. Moreover, there seems to be no tendency to quote special public health m.p.c.'s for chemically toxic substances (except in the case of beryllium). Therefore it is suggested that for adults in a population, and for purposes of averaging only, the maximum single intake by the inhalation route should be the same as for the occupational situation, i.e. approximately 2.5 mg uranium. The maximum single intake for children would be lower by a factor ranging up to about 10 depending upon age and kidney size, but on the other hand minute volume figures for air breathed at different ages vary by a factor of the same order,[10] so that the appropriate concentrations in air would be likely to be about the same as for adults.

Population exposure—inhaled insoluble uranium

There is usually some difficulty in deciding whether uranium to which a population may be exposed is in the soluble or insoluble form; if, however, exposure was definitely proved to be due to insoluble material only, then the hazard would appear to be mainly of a radiological character, with the lung as the critical organ. In this case the averaging rules as enunciated by the ICRP would, of course, apply.

INGESTED URANIUM

Ingested uranium—occupational and population exposure

Similar calculations can be made for ingested uranium, e.g.

m.p.c.$_w$ U(nat) soluble or insoluble (168-hr week) $= 2 \times 10^{-4}$ μc/cm^3 (ICRP 1959)
$= 6 \times 10^{-4}$ g/cm^3.

Daily amount ingested at m.p.c.
$= 6 \times 10^{-4} \times 2200$ g (assuming water intake = 2200 cm^3/day)
= 1.3 g (occupational) or 0.13 g (population exposure).

52-week exposure (ingested)
$= 0.13 \times 365 \doteq 47$ g (population exposure).

This again would seem to be much too much if ingested in one dose. A human volunteer ingested 1 g of uranyl nitrate hexahydrate in 200 cm^3 water (= 0.47 g uranium).[11] He experienced rather violent vomiting, diarrhoea and slight albuminuria with a peak uranium output in urine at the rate of 8 mg U/l. (on two specimens of 30 ml). In the first 7 days he excreted in his urine 2.5 mg of uranium element. It was thought therefore that he may have absorbed about 1 per cent of the ingested dose, i.e. much greater than the 10^{-4} fraction estimated by ICRP (1959) and based on animal work.[1] More recent work by FISH *et al.*[12] on dogs given uranyl fluoride in water by mouth, showed that uptake into the bloodstream averaged 1.5 per cent of the rather high dose administered.

It seems that the 1959 occupational m.p.c. for ingestion might have been rather high and that the irritative effect of these comparatively large amounts or uranium on the gastrointestinal tract may have been underestimated.* The occupational m.p.c. for ingestion is however only of interest as a measure of the gravity of an accidental ingestion in a radiation worker.

The more important figure to establish is the population dose for ICRP Group B(c) which an individual may ingest at one time. Evidence is lacking, but it is suggested that approximately one-third of the dose found to be irritating to the gut in the above experiment might be allowable, i.e. 150 mg uranium (measured as the element). This would be equivalent to averaging the maximum permissible exposure over 2 days if only fluid intake (1200 cm^3/day) is contaminated, but would represent a shorter time than this if total water intake (2200 cm^3/day) is contaminated.*

Since children's kidneys are about one-tenth the size of an adult's, it would seem logical to reduce the above intake by one-tenth for environmental use.* The weight of both kidneys in a new born baby is 20–30 g, whilst the weight of both kidneys in adults is 260–360 g.[13] The fluid intake of a baby is about

* *ICRP Publication* 6 has tackled these problems by reducing factor f_w (fraction reaching organ of reference by ingestion) from 10^{-4} to 10^{-8}, as well as by laying down maximum limits for inhalation and ingestion.

a fifth of that of an adult,[13] so that this factor partially compensates for the smaller size of a baby's kidneys relative to those of an adult.

PLANNED EMERGENCY EXPOSURES OF EMPLOYEES

It is suggested that 10 mg of soluble natural uranium inhaled over a short period would, on ICRP principles, lead to a total dose of 2.5 mg in the bloodstream (i.e. absorbed dose). This is somewhat less than the 0.1 mg/kg injected dose which LUESSENHOP *et al.*[5] mention as the nephrotoxic dose for man. Therefore a figure of 10 mg natural uranium in the total air breathed over a period might be considered as a reasonable "planned emergency exposure" in the ICRP sense. In effect this would be equivalent to administering nearly 5 days' dose at one time, but this dose would be subject to the rules of other planned emergency exposures.

ENRICHED URANIUM

For enriched uranium the principles discussed above would apply for the toxic effect, but the radiological effect on bone or kidney could be integrated in the ICRP way. The simplest solution is to express maximum single intakes of uranium in units of weight as above, and consider that these apply to any given enrichment of uranium.

Acknowledgment—I am grateful to a number of colleagues in the United Kingdom Atomic Energy Authority and to Dr. J. F. LOUTIT of the Medical Research Council, who have criticised an earlier draft of this paper.

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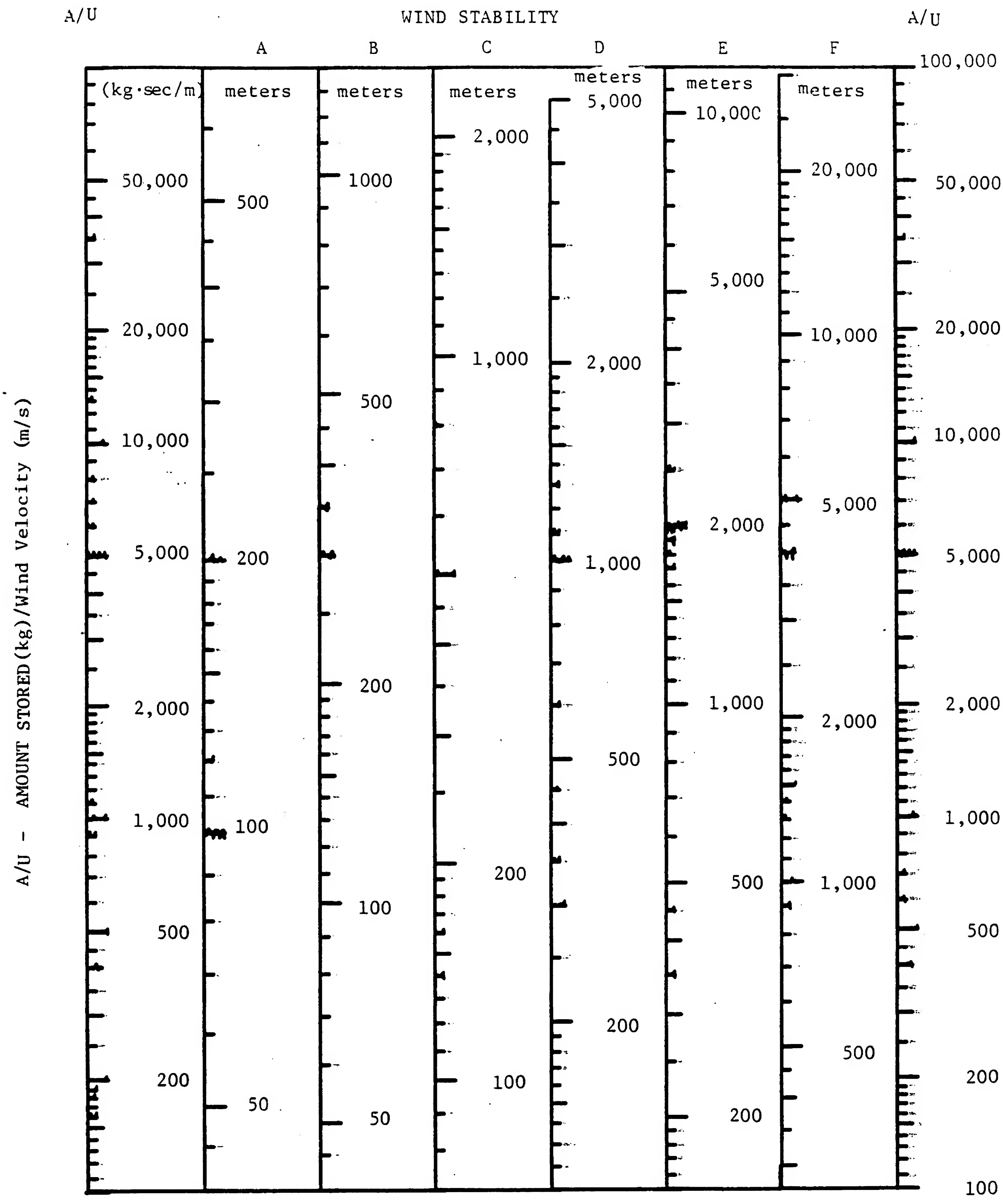
CONTROL BOUNDARY FOR FIRES

Amount Stored per unit wind velocity (A/U) kg sec/m	PASQUILL'S STABILITY CATEGORIES A	B	C	D	E	F
	DISTANCES km	km	km	km	km	km
100.	0.04	0.04	0.07	0.11	0.15	0.27
200.	0.05	0.06	0.09	0.16	0.24	0.44
500.	0.76	0.1	0.15	0.27	0.42	0.8
800.	0.94	0.13	0.2	0.36	0.56	1.1
1000.	0.1	0:14	0.22	0.4	0.64	1.3
2000.	0.14	0.19	0.31	0.56	1.	2.1
5000.	0.2	0.31	0.5	1.	1.9	4.
8000.	0.25	0.4	0.66	1.3	2.4	5.6
10000.	0.27	0.44	0.74	1.5	2.7	6.4
20000.	0.36	0.62	1.05	2.3	4.4	10.
50000.	0.52	1.	1.7	3.8	7.6	19.
80000.	0.64	1.25	2.2	5.	10.	27.
100000.	0.7	1.4	2.5	5.6	12.	31.


A/U
WIND STABILITY
A/U
A
B
C
D
E
F
(kg·sec/m)
meters
meters
meters
meters
meters
meters
A/U - AMOUNT STORED (kg)/Wind Velocity (m/s)
50,000
20,000
10,000
5,000
2,000
1,000
500
200
500
200
100
50
1000
500
200
100
50
2,000
1,000
200
100
5,000
2,000
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200
10,000
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2,000
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5,000
2,000
1,000
500
100,000
50,000
20,000
10,000
5,000
2,000
1,000
500
200
100

Inc. 3

DEPARTMENT OF THE ARMY
US ARMY MOBILITY EQUIPMENT RESEARCH & DEVELOPMENT COMMAND
FORT BELVOIR, VIRGINIA 22060

DRDME-VR

18 December 1981

SUBJECT: Setting Control Boundaries from Igloos Storing Pyrophoric Deptleted Uranium (DU)

Commander
US Army Materiel Development
and Readiness Command
ATTN: DRCSF-P
5001 Eisenhower Avenue
Alexandria, Virginia 22333

1. Inclosed is the report "Setting Control Boundaries from Igloos Storing Pyrophoric Depleted Uranium." This document details the physical, environmental, and regulatory grounds limiting exposure to toxic, airborne aerosols of Uranium-238 in the event of unplanned ignition and fire of associated munitions.

2. Point of contact for additional information is Michael Funkhouser, Autovon 354-5437 or Robert C. McMillan, Autovon 354-5133, this Command.

FOR THE COMMANDER:

Emil J. York

EMIL J. YORK
Chief, Material Technology Laboratory

CF: Cdr, AFMSC/SGPZ (Cpt Bollinger)
Cdr, DRDAR-SCN-P (Dr. Bloore)
Cdr, DRXOS-ES (L. Foley)
Cdr, HSE-RH (H. Edge)

SETTING CONTROL BOUNDARIES FROM
IGLOOS STORING PYROPHORIC DEPLETED URANIUM (DU)

1. PURPOSE:

a. A set of control boundaries are provided in this report and extend from stockpiles of munitions incorporating depleted uranium (DU) whether in storage or in transit. These boundaries minimize potential exposure to toxic, airborne aerosols of pyrophoric uranium.

b. These control boundaries represent a characteristic measurement of dose from an inhaled aerosol of uranium generated by an unplanned ignition of associated munitions. This measurement is a complex calculation. Viable regulatory limits must be assessed for a single acute emergency release of a radio-chemical agent. Significant population differences will mitigate toxic exposures to this agent. Physical characteristics of the agent, on-site storage configuration of associated munitions, and local micro-meteorological conditions will necessarily impact on the final dose commitment to any one individual at the control boundary.

2. REGULATORY LIMITS AND RADIOLOGICAL MODELS.

a. Current regulatory requirements limiting exposure to concentrations of airborne aerosols of uranium are derived from extensive research and industrial epidemiology. The Nuclear Regulatory Commission (NRC) has promulgated Table I, Appendix B, at 10 CFR 20 which limits weekly occupational exposure to aerosols of Uranium-238 (DU) at 0.2 mg/m^3 for a time integrated concentration (CT) factor of 8 $mg \cdot hr/m^3$.

b. Similarly the American Conference of Governmental Industrial Hygienists (ACGIH) has recommended a Threshold Limit Value of 0.25 mg/m^3 at references 1 and 2 (at paragraph 9) for airborne concentrations of uranium and its aerosols.

c. A significant proposal by I.S. Eve at reference 3, incl 1, suggests a maximum planned emergency inhalation for occupationally exposed persons to 10 mg of uranium. At a breathing rate of 1.25 m^3/hr, a maximum planned emergency CT factor of 8 $mg \cdot hr/m^3$ or 480 $mg \cdot min/m^3$ is calculated.

d. This value is consistent with both the Reference Man Model and the Task Group Lung Model as calculated by McMillan and Air Force at references 4 and 5. Although these models assess radiological toxicity, chemical toxicity to the kidneys following acute inhalation of somatic transportable DU at references 6 and 7 cannot be dismissed. Hence, a CT factor of 480 $mg \cdot min/m^3$ is not only conservative with respect to the radiological models as reported; it is also consistent with laboratory studies at references 1, 2, 7, 8, 9, 10 and 11 assessing nephrotoxicity following acute inhalation and ingestion of both soluble and insoluble uranium compounds in excess of 480 $mg \cdot min/m^3$.

3. PHYSICAL AND CHEMICAL PROPERTIES.

a. Uranium is a dense metallic white metal which is pyrophoric when finely divided. It oxidizes in air and dissolves in acidic solution. Natural uranium consists of three isotopes: U-234, U-235, and U-238. (The latter most is principally depleted uranium). Each is radioactive and chemically toxic. With a chemical valence of 3, 4, 5, or 6, uranium forms complex molecular salts, nitrates, oxides, and carbonates. Each form is relatively soluble depending on the pattern of physical entry into the body and its metallurgical state.

b. Solubility is greatly enhanced when uranium compounds are dissolved in carbonic solutions in finely divided grains. Once dissolved in extracellular fluids, a mildly acidic solution, uranium becomes a nephrotoxic agent to the kidneys an insoluble aerosols become a radiotoxic agent to the lungs. In particular, the soluble characteristics of aerosols of complex uranium oxides (UxOy) is discussed at reference 6. Up to 50% of aerosolized DU dissolves in simulated lung fluid (a carbonic solution) in seven-days. This fraction represents a transportable nephrotoxic dose of uranium to the kidneys. About 80% of this fraction is released to the urine in 24 hours at references 9 and 12. The remaining 20% is released from the kidneys with a biological half life of 15 days at reference 13. The non-transportable fraction of 50% represents a radiological dose commitment to the lungs with a biological half life of 380 days at reference 12. An evaluation of dose commitment follows at paragraph 8.

4. POPULATION CHARACTERISTICS AND DOSE RESPONSE.

a. An unplanned, spontaneous ignition of munitions incorporating quantities of DU in storage or transit may expose local populations including support personnel, to potentially toxic levels of airborne aerosols of uranium. Pertinent radiological limits, however, have been modelled on the concept of a radiation worker whose slightly elevated body burden of uranium is held constant by the particular retention and excretion dynamics which are characteristic of an adult (Reference Man ICRP 23). Such modelling is absent among a diverse population of infants, children, and adults of various consitutions with no significant body burden of uranium. The nephrotoxic limit of 3μgm/gm of kidney at references 2 and 5 is, however, uniformly applied throughout the population.

b. Unlike radiological limits which assume a linear response as dose approaches zero at reference 14, the nephrotoxic limit is a threshold effect characteristic of repairable, incipient kidney damage at reference 2 and 9. The maximum permissible occupational exposure from an actue, emergency release of airborne aerosols of uranium is, therefore, assumed applicable to a local population, not subject to chromic weekly exposures permitted among adult radiation workers.

c. The proposed control boundaries derived at paragraph 7 are consistent with NRC requirements and ACGIC recommendations limiting exposure to airborne aerosols of uranium. These boundaries are especially sensitive to on-site configuration and

storage parameters. Furthermore, the rate of oxidation, pyrotechnics, composition and design of the munitions, local meteorological conditions and effective emergency response to an unplanned incident will greatly mitigate upon any potential exposure. Relevant onsite and meteorological assumptions are proposed at paragraph 6.

5. ONSITE CONFIGURATION AND ASSUMPTIONS.

a. To assess the nephrotoxic fraction of somatic transportable (soluble) DU released to the plume during a fire, the following assumptions are consistent with references 6, 15 and 16:

(1) 30% of the rounds are "effected"; 70% are "uneffected."

(2) 50% of the rounds are aerosolized; 50% are deposited onsite.

(3) 50% of the aerosolized compounds are of respirable size; 50% are nonrespirable.

(4) 50% of the aerosolized compounds of respirable size are transportable (nephrotoxic limits); 50% are nontransportable (radiotoxic limit).

b. The somatic transportable nephrotoxic contribution to the kidneys is 3.75%. This fraction is the product of the effected, aerosolized, respirable and soluble fractions from compounds of uranium released to the plume following spontaneous ignition and fire of stored GAU-8 ammunition.

c. The somatic nontransportable radiotoxic contribution to the lungs is likewise 3.75%. This fraction is the product of the effected, aerosolized, respirable and insoluble fractions from compounds of uranium released to the plume.

6. MICRO-METEOROLOGY AND BOUNDARY LIMITS.

a. Aerosols of uranium are essentially trapped and carried by a plume whose displacement and configuration is characterized by the adiabatic lapse rate, atmospheric diffusion, radiant index, turbulence, and wind velocity. Such effects are subsumed in Pasquill's Stability Categories A, B, C, D, E, and F. Categories A, B, C, and D characterize normal daylight adiabatic lapse rates. A wind velocity of 1 m/sec (2.2 mi/hr) suggests an extremely unstable lapse rate designated A; at 3 m/sec, a moderately unstable rate of B; and at 5 m/sec or more, a slightly unstable or neutral rate of C or D.

b. Seasonal variations tend toward the unstable lapse rates during summer (A or B) and near neutral during winter (C or D).

c. Categories D, E, and F characterize nightime inversions. Light winds of less than 3 m/sec favor the moderately stable category of F, while winds greater than 3 m/sec favor the slightly stable category of D. Little seasonal variation is noted. Detailed theoretical and empirical studies can be found at references 17, 18 and 19 which can be adapted to local conditions.

d. In the absence of meteorological data, a daylight stability category of A may be considered for near calm. Categories B or C for perceptible breezy or windy conditions. At night, consider category F for near calm; otherwise, consider categories E or D for perceptible breezy or windy conditions.

e. In general, decreasing wind velocity will transport a plume with a given airborne concentration of aerosols an increased distance downwind through a narrowly defined sector of about 22.5 degrees. Similarly, a calm nighttime inversion will transport an airborne aerosol concentration an increased distance.

f. Practical control boundaries, therefore, may not assure an optimum limiting exposure to extremes in local meteorological conditions. However, the combination of numerous safety variables and probabilities of spontaneous ignition suggest the recommended control boundaries are practicable.

7. <u>DERIVED CONTROL BOUNDARY LIMITS</u>.

a. The derived control boundaries increase in inverse proportion to the integrated, time-concentration factor designated as D in units of $mg \cdot min/m^3$. The boundaries furthermore increase in direct proportion to the source strength. The source strength is the product of the amount of stored uranium in units of kilograms per unit wind velocity ($kg \cdot sec/m$) and the fraction of transportable uranium (3.75%) released to the atmosphere following spontaneous ignition and fire of stored ammunition.

b. To enclose a given exposure (D) in $mg \cdot min/m^3$, the derived control boundaries must gradually increase as the vertical atmospheric temperature gradient proceeds from an extremely unstable lapse rate to an extremely stable lapse rate (A through F). Graphs from Figures 4.3.1a. and b. through 4.3.6 a. and b. at reference 20 provide recommended boundaries for each of Pasquill's Atmospheric Stability Categorie.

c. Recommended control boundaries are provided at inclosure 2. These boundaries minimize potential exposure to nephrotoxic and radiotoxic aerosols of uranium during a fire for each stability class A through F.

d. Initial conditions which minimize toxic exposures follow from recommended CT factor as developed at paragraph 2. Higher exposures result as control boundaries are reduced. Similarly, higher exposures result as the product of the source strength and the fraction of transportable uranium released from a fire increases. Higher wind velocity effectively reduces the source strength on account of increased atmospheric mixing with a longer volume of air.

e. To set initial control boundaries upon ignition and fire of GAU-8 munitions, use the nomograph at inclosure 3 and make the following assessment:

(1) Determine the mass (kg) of depleted uranium at storage site which is in conflagration.

(2) Determine the wind speed, direction, and atmospheric stability class from onsite instrumentation.

DEPARTMENT OF THE ARMY
ARMY MATERIALS AND MECHANICS RESEARCH CENTER
Watertown, Massachusetts 02172

AMMRC SAFETY PROCEDURE
No. 385-24

4 January 1982

STANDING OPERATING PROCEDURE
HANDLING AND PACKAGING OF
DEPLETED URANIUM WASTE

1. Purpose. To prescribe specific procedures for handling and packaging depleted uranium waste at AMMRC (hereafter designated as DU).

2. Scope. Applicable to all personnel involved with handling and packaging of DU waste.

3. Policy. All handling and packaging of DU waste will be in such a manner as to minimize radiation exposure to personnel, spread of contamination and volume of waste generated.

4. Responsibilities. a. Chiefs of organizations and/or labs generating DU waste are responsible for:

(1) Complying with and enforcing the handling and packaging requirements prescribed in this safety procedure.

(2) Assuring that his/her personnel are properly instructed and trained in the requirements for handling and packaging of DU waste.

(3) Providing necessary space, facilities and supplies for the proper handling and packaging of DU waste.

b. Supervisors of workers who generate, handle, and package DU waste are responsible for:

(1) Assuring that his/her personnel are instructed in requirements for handling and packaging of DU waste, and compliance with applicable rules, and regulations governing radiological waste packaging.

(2) Assuring that required monitoring devices, protective clothing, and equipment, and contamination methods are used.

(3) Notifying the Radiation Protection Officer, (hereafter designated as RPO), prior to the sealing of any DU waste barrel.

(4) Assuring that no liquids of any kind are contained within a DU waste barrel.

(5) Assuring that all waste barrels are lined with a 4 mil or heavier poly bag.

(6) Assuring that DU waste volume is minimized through recycle and compaction techniques.

c. The RPO is responsible for:

(1) Verifying contents of all DU waste barrels.

(2) Assuring that packaging is in compliance with all applicable regulations.

(3) Assuring that barrels are sealed properly.

(4) Assuring that the proper procedures are being followed for the handling and packaging of DU waste.

5. Procedures. a. General handling and packaging of DU waste and DU contaminated trash.

(1) Large DU pieces, (i.e., rings, slugs, cuttings) will be recycled where practicable.

(2) New 17-H type yellow barrels (30 or 55 gallon) will be utilized.

(3) Each container will be lined with a 4 mil or heavier poly bag.

(4) No liquids will be placed in any waste container.

(5) Shopcoats, gloves, and film badges will be worn while packaging waste.

(6) All DU contaminated trash will be compacted to reduce volume of waste prior to packaging.

(7) DU waste barrels (55 gallon) shall not exceed 600 lbs., gross weight.

(8) Only heavy duty retaining rings and 5/8-inch bolts will be used. Each bolt will be fitted with a lock nut, tightened, and secured by "staking" the threads.

(9) The RPO will inspect all full waste barrels, prior to sealing, for disposal.

b. DU Machine Turnings, (including chips, particles and small pieces).

(1) Turnings will be poly-bagged at the end of each work day and submerged in water until incineration.

(2) Incineration will be performed in accordance with AMMRC SOP No. 385-23, "Incineration of Depleted Uranium Machine Turnings, Building 43".

c. DU Remelt Slag.

(1) DU remelt slag will be allowed to decay to minimize radiation exposure.

(2) DU remelt slag will be submerged in water during the decay cycle. (At least six half-lives or approximately 145 days).

(3) Upon completion of decay cycle, the remelt slag should be handled the same as DU machine turnings.

D. DU Liquid Wastes.

All DU liquid wastes will be referred to the RPO for monitoring, prior to disposal.

6. All DU waste barrels, upon completion of prescribed packaging, will be transferred to the RPO for secure indoor storage pending disposal.

1 Incl
as

G. Bruggeman

Chief, Prototype Development Division

John F. Vining IV

Acting Chief, Safety Office

TABLE I FOR STABILITY CLASS B

CONCENTRATION-TIME FACTOR

Source Strength	25 mg-hr/m**3	8 mg-hr/m**3	2.5 mg-hr/m**3
	Distances		
kg-s/m	km	km	km
100	0.144	0.255	0.454
200	0.206	0.36	0.628
500	0.323	0.566	0.936
800	0.405	0.693	1.124
1000	0.454	0.758	1.224
2000	0.627	1.02	1.591
5000	0.936	1.452	2.227
8000	1.117	1.74	2.607
10000	1.219	1.893	2.809
20000	1.585	2.4	3.569
50000	2.226	3.268	5.066
80000	2.609	3.841	6.196
100000	2.796	4.189	6.77

TABLE II FOR STABILITY CLASS D

CONCENTRATION-TIME FACTOR

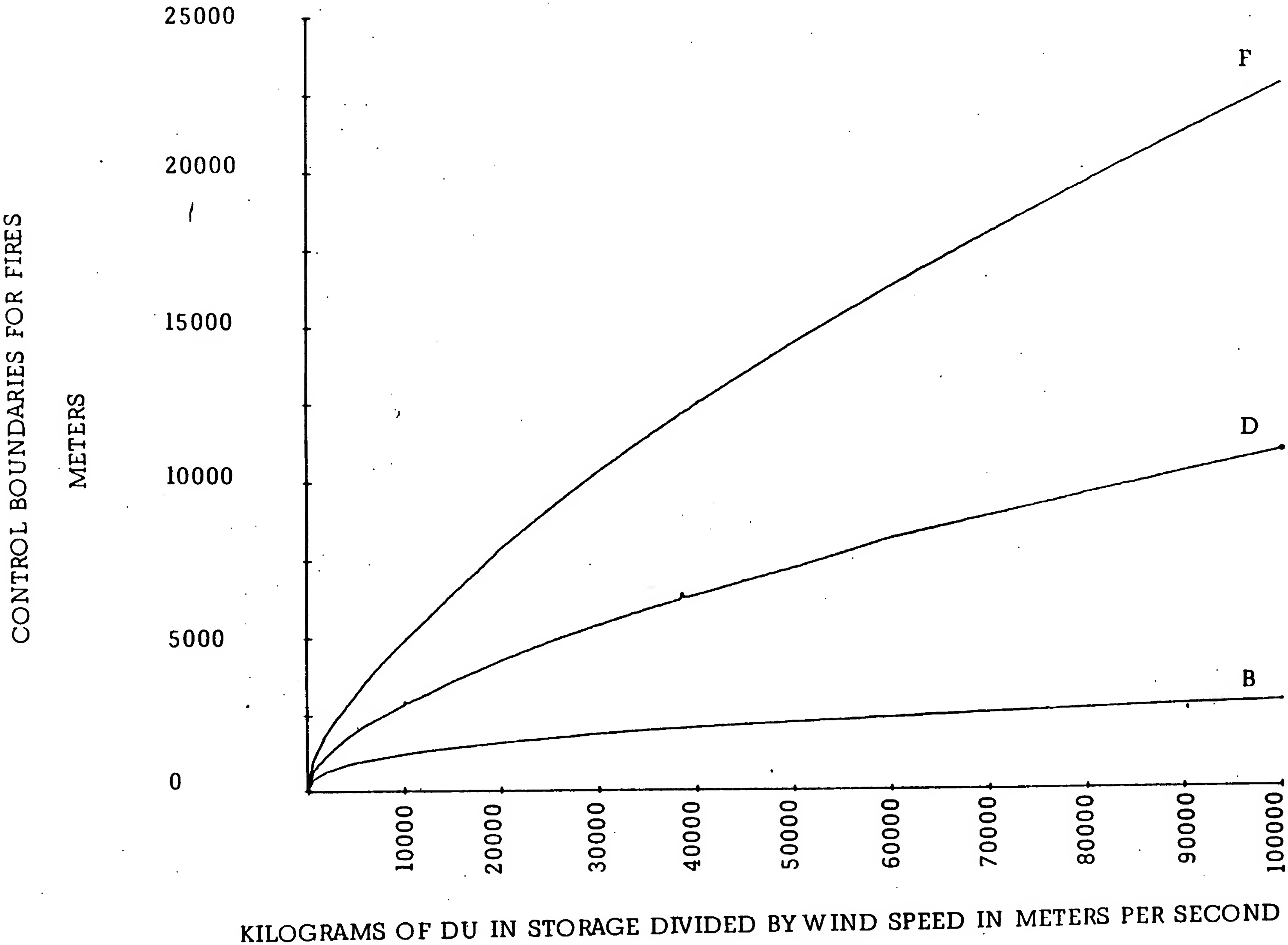
Source Strength	25 mg-hr/m**3	8 mg-hr/m**3	2.5 mg-hr/m**3
	Distances		
kg-s/m	km	km	km
100	0.217	0.392	0.777
200	0.321	0.603	1.149
500	0.532	0.994	1.956
800	0.696	1.308	2.528
1000	0.781	1.49	2.843
2000	1.146	2.204	4.247
5000	1.95	3.664	7.227
8000	2.512	4.854	9.505
10000	2.828	5.518	10.804
20000	4.253	8.311	16.353
50000	7.203	14.144	28.336
80000	9.514	18.741	36.544
100000	10.867	21.42	41.441

TABLE III FOR STABILITY CLASS F

CONCENTRATION-TIME FACTOR

Source Strength kg-s/m	25 mg-hr/m**3 km	8 mg-hr/m**3 km	2.5 mg-hr/m**3 km
	Distances		
100	0.356	0.654	1.252
200	0.516	0.949	1.895
500	0.834	1.637	3.14
800	1.095	2.149	4.299
1000	1.248	2.417	4.912
2000	1.896	3.663	7.92
5000	3.133	6.58	14.384
8000	4.289	9.13	19.555
10000	4.916	10.555	22.663
20000	7.897	16.666	35.9
50000	14.441	30.387	65.427
80000	19.61	41.598	87.065
100000	22.727	47.986	100.648

FIGURE 1. BOUNDARIES FOR DIFFERENT STABILITY CLASSES



STABILITY CLASS B

When Stability Class is unknown use F.
When Wind Speed is unknown use 1 meter per second.

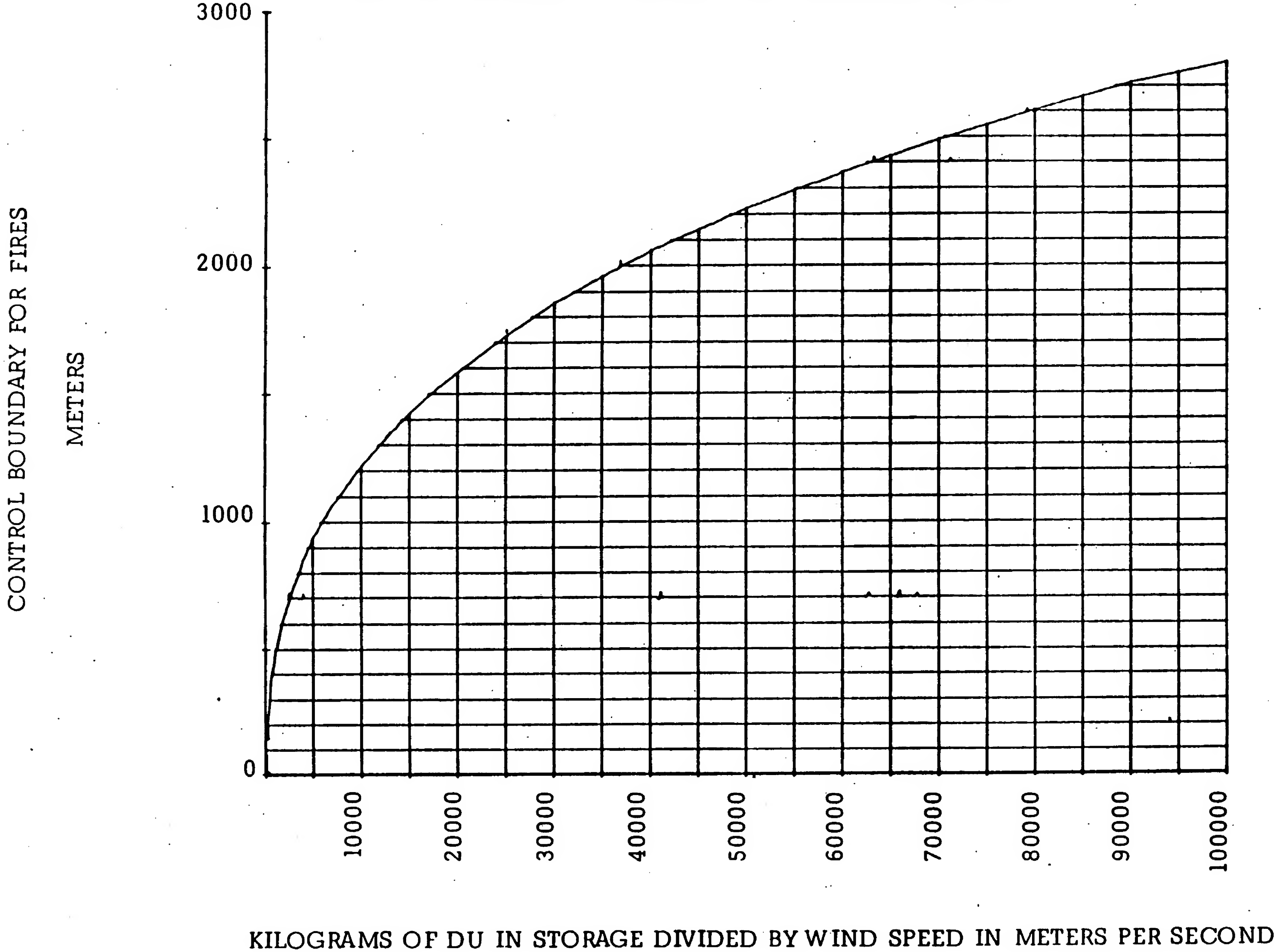
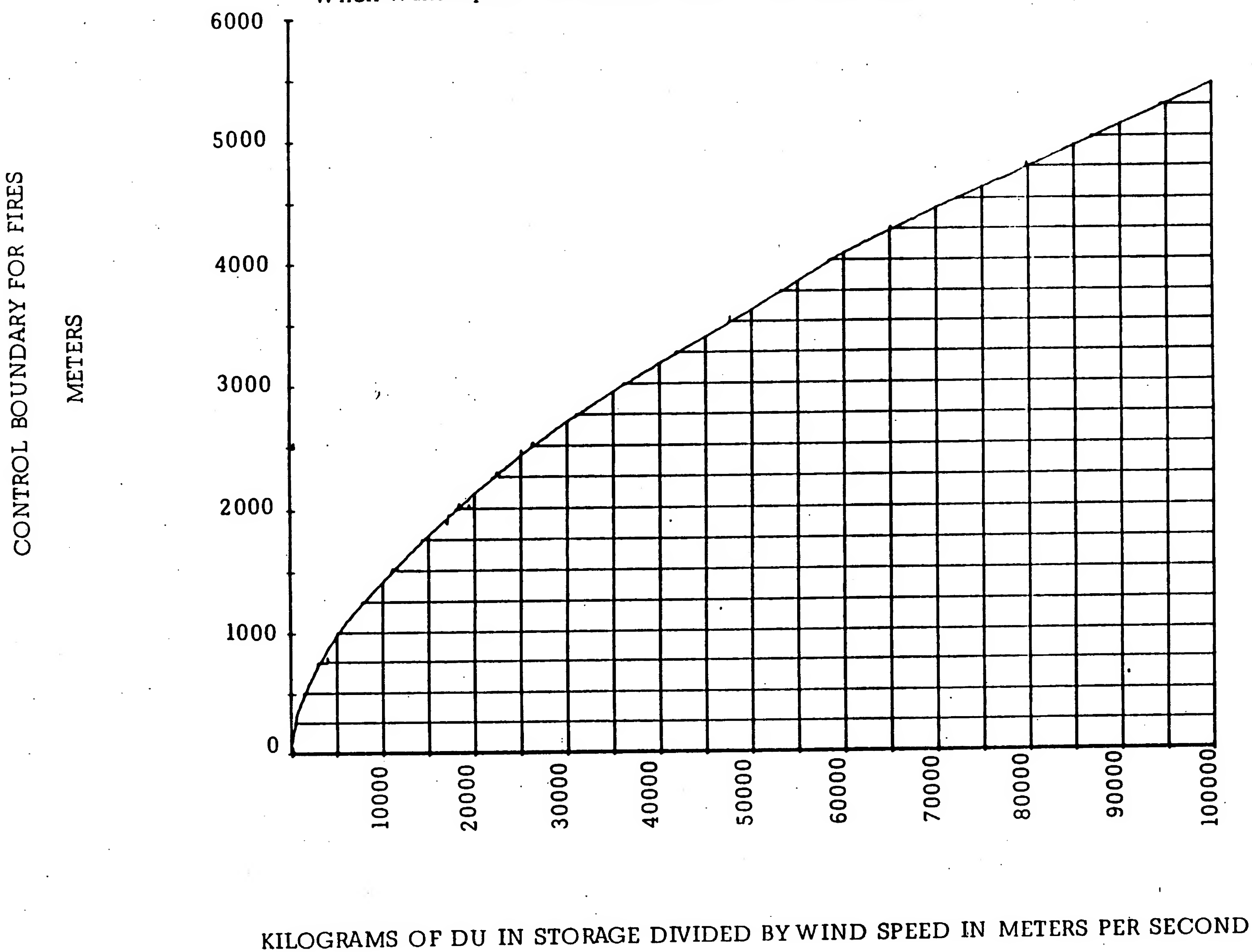


FIGURE [illegible]

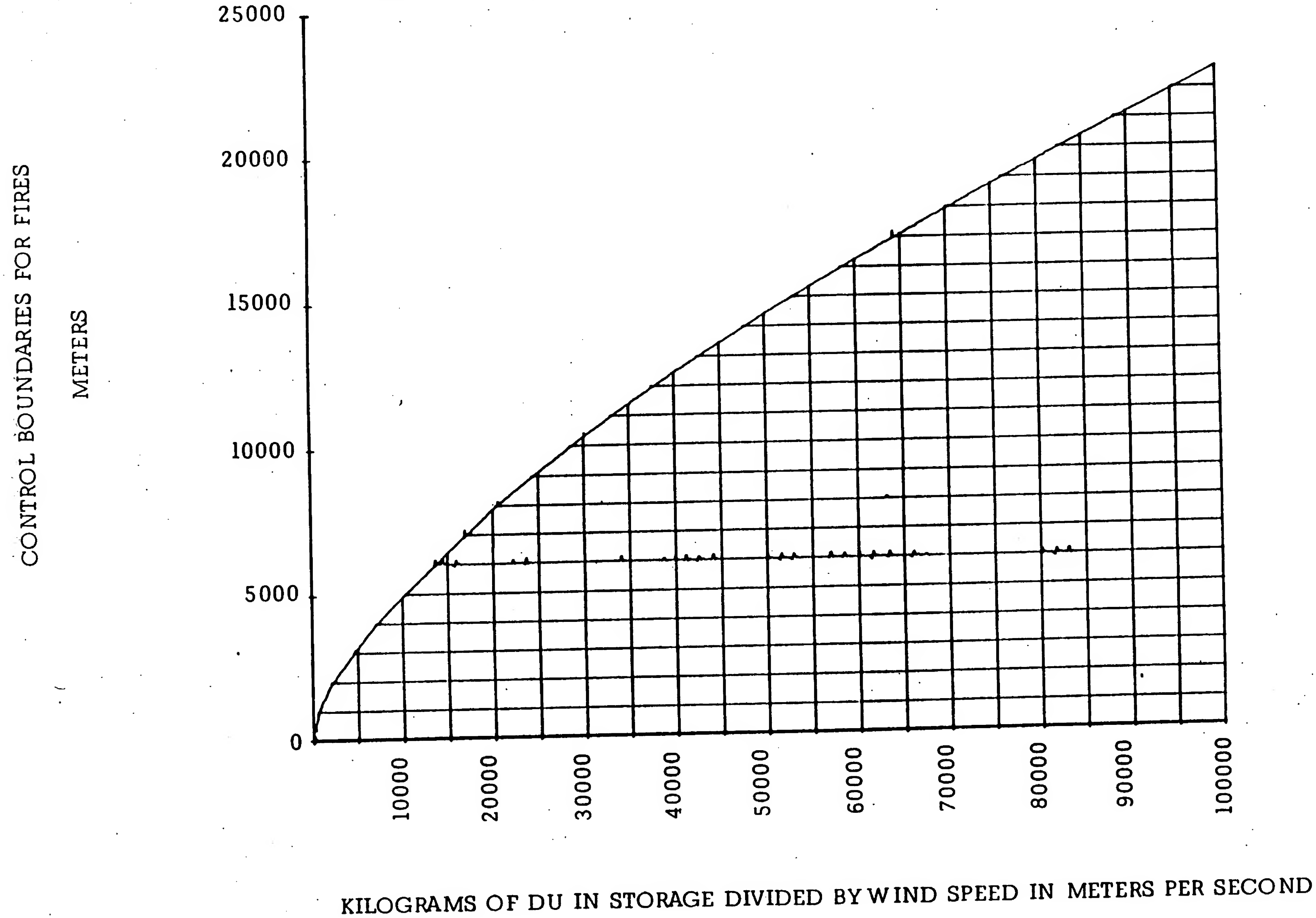
STABILITY CLASS D

When Stability Class is unknown use F.
When Wind Speed is unknown use 1 meter per second.



STABILITY CLASS F

Use this chart when stability class is unknown.
When Wind Speed is unknown, use 1 meter per second.



DEPARTMENT OF THE ARMY
ARMY MATERIALS AND MECHANICS RESEARCH CENTER
Watertown, Massachusetts 02172

AMMRC PAMPHLET
No. 385-37

22 March 1978

Safety
SAFE HANDLING OF DEPLETED AND NATURAL URANIUM

Paragraph

1. PURPOSE. To prescribe specific procedures pertaining to the handling and storing of depleted and natural uranium.

2. SCOPE. The provisions of this pamphlet outline minimum safety measures to be adhered to by all AMMRC personnel involved in handling or processing depleted or natural uranium.

3. POLICY. It is the policy of this Center to minimize personnel exposure, both external and internal, to uranium and uranium compounds, and to maintain radiation exposures to as low as reasonably achievable (ALARA).

4. DEFINITIONS. a. In this pamphlet "uranium" will refer to both depleted and natural uranium material.

b. "Radiation Work Permit" (RWP), XMR Form 311, is the prescribed form for written approval of certain work to be performed in restricted areas. (Figure 1)

c. In this pamphlet "respirator" will refer to only those respiratory protective devices approved by the National Institute for Occupational Safety and Health (NIOSH) for use in atmospheres containing radioactive contaminants.

5. RESPONSIBILITIES. a. The Radiation Protection Officer, (RPO), is responsible for reviewing procedures, making surveys and providing advice and assistance to uranium users and insuring compliance with regulations and approved procedures.

*This Pamphlet supersedes AMMRC Procedure 385-37, dtd 27 July 1972.

b. Chiefs of Organizations Using Uranium are responsible for complying with and enforcing requirements prescribed in this pamphlet which are applicable in all uranium processing areas.

c. Supervisors are responsible for:

(1) Assuring that his personnel are properly instructed and trained in the requirements for working with and handling uranium and for insuring that employees comply with all applicable rules and regulations.

(2) Assuring that required monitoring devices, protective clothing and equipment are used by personnel in uranium processing areas.

(3) Assuring that all personnel under his control, who are assigned to work with uranium, are placed on the Occupational Health Roster for uranium.

d. The individual is responsible for being familiar with all safety requirements established in this procedure for complying with such requirements.

6. PERSONNEL PROTECTION. a. Protective clothing consisting of shopcoats, coveralls, trousers and shoe coverings are to be worn by personnel working in uranium processing areas designated as contamination control areas or as otherwise specified by the RPO.

(1) Protective gloves will be worn when handling rough pieces of metallic uranium and other contaminated items.

(2) An adequate supply of protective clothing will be maintained in uranium operating areas. Special care will be taken to deposit contaminated clothing in containers provided for that specific purpose.

(3) Respirators will be worn by personnel whenever required and in new operations. Respirators will be surveyed and decontaminated after each use and placed in a polyethylene bag.

b. To insure that personnel exposures are kept ALARA, the following general precautions will be followed:

(1) All personnel will remove protective clothing in the designated clothing change areas. Protective clothing, other than pants, must not be worn outside processing of change areas.

(2) Personnel will wash their hands and face before leaving uranium processing facilities.

(3) No eating, drinking, or smoking is allowed where contamination is present.

(4) Approved warning signs, containing a three bladed propeller and also including the warning - "Caution Radiation Area", and/or "Caution - Radioactive Materials", in magenta on a yellow background will identify each radiation area, and will be posted on a permanent basis.

(5) Uranium processing areas will be locked at all times during the absence of operating personnel.

c. All personnel working in uranium areas shall wear personnel monitoring devices specified by the RPO while working in such areas. These badges will not be removed from the uranium facility but will be stored in a location designated by the RPO. The RPO will provide the required film badges and/or thermoluminescent dosimeters (TLD) to assigned personnel and will change the monitoring devices periodically.

7. SAFETY PRECAUTIONS IN PROCESSING URANIUM. a. General. (1) All operations will be conducted in a very clean shop. The operation areas shall be mopped or vacuum cleaned when in use. Sweeping, which raises dust, is prohibited.

(2) Decontamination of areas and machines will be performed upon determination by the R&OSB that it is required or when existing conditions approach the maximum contamination level permitted. General cleaning will be performed daily.

b. Machining Uranium. (1) Machining of uranium and uranium alloyed components will be performed on machines designated for that purpose. Machines used in processing uranium will be so identified and segregated in specific areas. Special procedures must be submitted to and approved by the R&OSB whenever material, other than uranium, is machined on uranium processing equipment.

(2) All equipment and materials will be decontaminated prior to removal from uranium processing areas. The R&OSB will determine whether the decontamination has been successful.

(3) Operators will take all necessary precautionary measures to prevent uranium chips from igniting.

(a) Machining will be done at minimum practical speeds with sharp tools.

(b) Generous use of coolant and properly grounded tools shall be required. Corrosion problems concerning lathe beds and other machinery parts will be eliminated by replacing the soluble oil coolant with water soluble chemical base coolants such as "K-7" or "Cimcool".

(c) The maximum accumulation of uranium chips allowed on a machine and/or in the scrap bucket at any one time should not exceed 10 pounds.

(4) The following prcedure will be adhered to in removing chips and cuttings from machines:

(a) Place a heavy duty 18" x 24" plastic bag into a 5 gallon can. The weight of the can is to be predetermined to the nearest one tenth of a pound.

(b) Remove uranium chips and turnings from the machine and place them into the plastic bag and 5 gallon can.

(c) Weigh the 5 gallon can and its contents and note the total weight. The net weight of the uranium is obtained by subtracting the weight of the 5 gallon can and plastic bag from the total weight making allowances for alloy contents. Record the net weight of uranium.

(d) Transfer the contents of the 5 gallon can into a 30 gallon barrel located outside the east door bay area, Bldg. 312.

(e) At the end of the workshift, the barrel of chips and turnings will be transfered to a designated storage area for incineration. Pyrophoric uranium chips and turnings must not be kept in Building 312 overnight.

(f) The gross weight, the net uranium weight, and the words "CHIPS FOR INCINERATION" will be marked on masking tape applied to the side of the barrel.

c. Melting Uranium. (1) R&OSB will be notified whenever a melt is to be performed.

(2) Additional controlled areas will be set up where appropriate during uranium melting operations to minimize the spread of contamination.

(3) Respirators and protective clothing will be worn when removing a uranium melt from the furnace and when working on the downdraft table. Care will be taken to keep airborne particulate to a minimum when removing the mold from the furnace. A downdraft table will be used when removing cast uranium from the mold or cleaning uranium castings.

(4) Exposure to uranium slag should be limited because of slag dose rates up to 20 Rad/hr.

d. Forging Uranium. (1) Controlled areas will be set up for all uranium forging operations to control the spread of air and surface contamination.

(2) Protective clothing will be worn during uranium forging operations. Respirators will be worn during forging operations unless it has been determined that respirators are not required.

e. Ventilating and Exhaust Systems. (1) In addition to area ventilating systems, machines should be equipped with approved permanent or portable venti ting and exhaust systems to keep uranium airborne concentrations at a minimum.

(2) Air sampling will be conducted by the RPO on a periodic basis. Air sampling is also mandatory for all new operations.

f. Sludge in coolant reservoirs and solid wastes from vacuum cleaner sweepings and exhaust filters will be handled as radioactive waste. Pyrophori material will be incinerated along with uranium chips and turnings.

g. No new operations will be undertaken without prior approval of the R&OSB.

8. RADIATION WORK PERMITS. a. A RWP is required for work performed in uranium processing areas under the following conditions:

(1) For work by personnel assigned to these areas, not covered by an operating procedure approved by the R&OSB.

(2) For work performed by personnel not permanently assigned to these areas, involving a radiological hazard.

b. All work permits will expire on the last normal working day of the month during which they are issued, unless otherwise stated on the RWP.

c. The initiation and use of the RWP is the responsibility of the person requesting or requiring the work. Part II of the RWP is used in conjunction with a high radiation field, where time limitations will be imposed, or a contaminated area, and is the responsibility of the RPO.

d. The following procedure will be used in filling out RWP's:

(1) RWP's will be provided by the R&OSB upon request.

(2) The person requesting to do work or have work done, which requires a RWP, will complete Part I to the extent possible and will list the names of personnel doing the work in Part II. The RWP will be submitted in triplic to the RPO.

(3) The RPO will designate necessary special instructions and approve th RWP. Part II of the RWP need only be completed by the RPO if the radiation field encountered in the work area will necessitate restricting the time personnel are mitted in the area, or if contamination is expected.

(4) The RPO will retain the second copy of the RWP and will return the other two copies to the requesting organization. The requestor will retain the first copy for his files while the third copy is to be retained at the work site.

(5) At the completion of the job, the third copy of the work permit will be signed by the requestor and returned to the RPO.

9. VISITORS. a. No visitors will be admitted in uranium processing areas without express permission from the Chief of the particular organization.

b. Precautions will be taken so that visitors receive minimal exposure to ionizing radiation and airborne concentrations of radioactive particulate.

c. Visitors will wear prescribed personnel protective equipment when entering uranium processing areas.

d. Visitors must be accompanied by authorized personnel at all times and a record made of date and length of visit.

10. EMERGENCY PLAN. a. In the event of a uranium fire certain precautions must be observed. Radiation contamination may be spread by explosion, smoke, or any other by-products of fire of firefighting, as well as inadvertant tracking of radioactive material by personnel or equipment.

b. At least two Melt-X fire extinguishers will be maintained in the working areas. Water should not be used for fighting uranium fires. Two clean respirators restricted for use in firefighting will be maintained in a clean plastic box located above each extinguisher.

c. In the event of fire, personnel on duty will attempt to control local fires with extinguishers while wearing properly fitted respirators. Personnel shall also immediately notify Security (ext 33158), the Building Fire Marshal, the area supervisor, and the R&OSB (ext 33225 or 33605).

d. Normal operations will not be resumed until the Chief, R&OSB and the Fire Marshal have determined that the hazardous conditions have been brought to safe operating levels.

e. Semi-annual drills will be conducted by the organization Chief. Drills will include the use of emergency respiratory and other protective equipment. A summary report of each drill will be furnished to the Chief, R&OSB.

11. RADIATION SAFETY SURVEYS. Supervisors of areas processing uranium where levels of contamination may exceed the established "clean limits", will survey their areas at least weekly to insure that their operations are within limits prescribed by AMMRCM 385-4. Surveys may consist of the following:

RADIATION WORK PERMIT and HEALTH PHYSICS INSTRUCTIONS

No._____

For Maintenance and Service Operations

PART I (Complete in Duplicate)

Building________________ Location________________________________

Description of Project: ____

____

Special Instructions

- ☐ Notify________________before starting work.
- ☐ Hand and foot counts required before leaving Radiation Area.
- ☐ No cuts or abrasions on hands or forearms.
- ☐ Tool check at completion of work.

Protective Equipment	
Coveralls	
Lab. Coats	
Chino Pants & Shirt	
Rubber gloves	
Cloth gloves	
Issued shoes	
Shoe covers	
Head covering	
Respirator	
Fresh Air Mask	
Paper clothing	

SURVEY: At start of work ☐ Continuous ☐

Approved: ____________________ Date________________ Time__________
Area Supervisor

____________________ Date________________ Time__________
Health Physicist

PART II

SURVEY:

Area	mrem/hr.	Time in Area	
		Hrs.	Mins.

Radiation Work Time Record

Name	Pay-roll No.	Dosi-meter No.	In	Out	Dose (mrem)	Contamination:			Decontaminated		
						Hands	Shoes	Clothes	Hands	Shoes	Clot

a. Area surveys by swipe and instrument readings. Swipes will be read on the Tracerlab ratemeter or equivalent. Results will be recorded.

b. Surveys of all materials leaving the controlled area.

(DRXMR-AR)

FOR THE DIRECTOR:

OFFICIAL:

W. R. BENOIT
COL, TC
Commander/Deputy Director

PETER W. LICHTENBERGER
CPT, QMC
Adjutant

DISTRIBUTION:
B
R&OSB (50 cy)
MAD (75 cy)

(a) Judge atmospheric stability class from outline at paragraph 6; otherwise assume stability class F.

(b) Read wind conditions from appropriate instruments: otherwise assume wind speed of one (1) meter per second (m/s).

(3) Divide the amount (A) of burning mass of depleted uranium by the wind speed (U) to obtain (A/U) in units of (kg·sec/m).

(4) Use the nomograph and connect the value of (A/U) to either side of the graph and read the initial control boundary in meters for a specific atmospheric class.

f. The graphs from Figures 4.3.1a. and b. through 4.3.6a. and b. at reference 20 may be directly utilized by making the following adjustments in nomenclature:

(1) Replace D in figures with (CT) at paragraph 2.

(2) Replace Q(mg) in figures with A(mg)·f (Amount stored·somatic (non)transportable fraction from fire and deposited to the (lung)kidney) at paragraphs 5 and 7.

(3) Replace DU/Q in figures with (CT)·U/A·f = (CT)/(SS) where the source strength (SS) is (A·f/U) and U is the wind speed in meters per second (m/s).

(4) The quantity (CT)/(SS) decreases as a function of the reciprocal of the the distance in meters (m).

8. RADIOLOGICAL IMPLICATIONS AND POPULATION DOSE.

a. The dose commitment to the lungs is proportional to the infinite time integral of absorbed activity (μCi) from T = 0, following a single, acute inhalation of somatic nontransportable aerosols of uranium. This calculation assumes insignificant previous accumulation and no additional accumulation is assumed.

b. The activity (A) present in the lungs decreases at an exponental rate with time, or

$$A(t) = A_o e^{-\lambda_s T}$$

where A_o is the inhaled activity deposited to the lungs from somatic nontransportable uranium, by the relation

$$A_o(\mu Ci) = CT\left(\frac{mg \cdot hr}{m^3}\right) \times V\left(\frac{m^3}{hr}\right) \times SpA\left(\frac{uCi}{mg}\right) \times f_i$$

where CT is the integrated time-concentration factor as developed at paragraph 2,

V is the ventilation rate of $1.25 m^3/hr$ ref. (ICRP),

SpA is the specific activity for Uranium-238 of $0.333\ \mu Ci/10^3 mg$ of DU,

f_i is the insoluble, nontransportable, fraction deposited in the lungs as developed in paragraph 5,

and

λ_ε is the effective elimination rate of ln2/380 days (ref. 12).

Upon substitution and evaluation of the numerical constants, the inhaled deposition is

$$A_o = 8.0\ \frac{mg.hr}{m^3} \times \frac{1.25 m^3}{hr} \times \frac{0.333 uCi}{10^3 mg} \times 0.0375$$

$$A_o = 1.25 \times 10^{-4} uCi$$

c. The dose equivalent (DE) rate to the lungs in units of mrem/day follows the differential relation

$$\frac{d}{dt} DE\left(\frac{mrem}{day}\right) = A_o e^{-\lambda_\varepsilon T} (\mu Ci) \times \mathcal{E}\left(\frac{MeV \cdot rem}{dis \cdot rad}\right) \times \frac{1}{m(gm)} \times$$

$$\left[\frac{10^3 mrem}{rem} \times 1.6 \times \frac{10^6 erg}{MeV} \times \frac{gm \cdot rad}{100 erg} \times \frac{86400\ sec}{day} \times 37 \times 10^3\ \frac{dis}{sec \cdot \mu Ci}\right]$$

where

$\mathcal{E}$ is the effective absorbed energy per disintegration of 43 MeV·rem/dis·rad for Uranium-238 (DU)

and

m is the mass of the lungs of 1000 gm. Upon substitution and evaluation of the numerical constants of proportionality in brackets, the dose equivalent rate to the lungs becomes

$$\frac{d}{dt} DE\left(\frac{mrem}{day}\right) = 2.2 \times 10^3\ A_o e^{-\lambda_\varepsilon T}$$

d. Solution to the infinite time integral of absorbed activity from t = o becomes the dose commitment to the lungs or

$$DE(mrem) = \frac{2.2 \times 10^3 A_o}{\lambda_\varepsilon} (1-e^{-\lambda_\varepsilon T})$$

where

$$A_o = 1.25 \times 10^{-4} uCi$$

$$\lambda_\varepsilon = \ln 2/380 = 1.82 \times 10^{-3}\ day^{-1}$$

(1) In one year the dose commitment to the lungs is:

$$\frac{DE(mrem)}{1yr} = \frac{2.2 \times 10^3\ (1.25 \times 10^{-4} uCi) \cdot day \cdot (1-\exp(-1.82 \times 10^{-3}}{1.82 \times 10^{-3}}$$

$$\times 365))\frac{(mrem)}{uCi.day}$$

$$= 73.3\ mrem$$

(2) In 50 yrears the dose commitment to the lungs is

$$\frac{DE(mrem)}{50yr} = 2.2 \times 10^3 \frac{(1.25 \times 10^{-4})}{1.82 \times 10^{-3}}$$

$$= 151\ mrem$$

e. The derived annual dose commitment to the lungs following a single, acute inhalation of aerosols of uranium is less than 15% permitted nonoccupationally exposed individuals. If the assumptions at paragraph 5 are reliable, one may be tempted to augment the nontransportable fraction of activity deposited to the lungs as developed at paragraph 2 by enhancing the CT factor and reduce the derived control boundaries proportionately. A six fold increase in the CT factor from 8 to 48 $mg \cdot hr/m^3$ results in an annual dose commitment to the lungs of 6 x 73.3 mrem or 440 mrem. Although less than the permitted annual nonoccupational dose, a six fold increase represents an acute insult of 10mg x 6 x 0.0375 or 2.25mg of somatic transportable (soluble) uranium to the kidneys. This exceeds the maximum permissible uranium limit to the adult size kidney which is 0.9mg; and it greatly exceeds the permissible uranium limit to the infant size kidney which is 0.165 at references 2 and 5.

f. If the assumptions at paragraph 2 are reliable, an increase in the somatic nontransportable radiotoxic contribution to the lungs from 3.75% to 22.5% at paragraph 5 would yield the same nephrotoxic and radiotoxic values of 2.25mg and 440 mrem respectively. Indeed an increase from 3.75% to 9% would match the adult limit: 10mg x 0.09 = 0.9mg. An acute insult of 10mg at a deposition fraction of 3.75% delivers 0.375mg to the kidney which is the child's nephrotoxic limit.

g. It is therefore the enhanced nephrotoxic sensitivity that governs the derived control boundaries at paragraph 7 while committing a nominal non-occupational radiological dose to an exposed population.

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SOME SUGGESTED MAXIMUM PERMISSIBLE SINGLE INTAKES OF URANIUM

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Abstract—The Recommendations of the International Commission on Radiological Protection (1959) give maximum permissible concentrations for uranium in air and water, but before the issue of *ICRP Publication* 6 in 1964, there were no instructions concerning the time over which MPC's based on chemical toxicity of uranium might be averaged. The present paper, which was circulated informally in the U.K. Atomic Energy Authority before the issue of *ICRP Publication* 6, makes some suggestions regarding [redacted] for instance:

(a)	Maximum single intake of inhaled uranium in 1 day	2.5 mg
(b)	Maximum single intake of ingested uranium in 1 day	150 mg
(c)	Maximum planned emergency inhalation for occupationally-exposed persons	10 mg

The first two of these suggestions are now in line with the recommendations of *ICRP Publication* 6.

INTRODUCTION

The 1959 *Report of ICRP Committee* II[1] stated that "over a period of 13 weeks, the [redacted] present in air or in water [redacted] during any 13-week period [redacted] by exposure at the constant levels indicated in subsection 1 above." *ICRP Main Commission Report* (1959)[1] indicated that doses averaged over 13 weeks should be measured in rems and therefore presumably this did not provide for [redacted] rather, than to radioactivity. Paragraph 52 (f) of *ICRP Publication* 6[2] now lays down limits for the inhalation of not more than 2.5 mg of soluble uranium in 1 day, or the ingestion of not more than 150 mg of soluble uranium averaged over 2 days. The consequences of inhaling or ingesting a 13-week dose of uranium in a short period of time, before these limits were applied, are discussed below.

INHALED URANIUM

Radiation workers—inhaled soluble uranium

If a natural uranium airborne exposure at the maximum permissible level was averaged over 13 weeks the result would be as follows:

$$\text{m.p.c.}_a\ \text{U(nat) (soluble)} = 7 \times 10^{-11}\ \mu c/cm^3 = 210\ \mu g/m^3\ \text{(40-hour week m.p.c.)}.$$

If this is integrated over 13 weeks or 65 working days, then exposure $= 210 \times 10 \times 65\ \mu g$ inhaled $= 136$ mg U inhaled in one incident (10 m^3 air inhaled/day).

Twenty-five per cent of this goes to the blood stream, i.e. 34 mg (ICRP model).

Approximately 50 per cent of this would be excreted in less than 24 hr,[3] say in 1 l. of urine. Therefore urine would contain 17 mg/l. uranium (natural).

U.K. Atomic Energy Authority experience as quoted by Butterworth[4] shows that from a single exposure to uranium several mg/l. of uranium in urine would produce albuminuria, although prolonged exposures would produce albuminuria at lower levels of a few hundred μg/l. of uranium. One case of acute UF_6 inhalation seemed to produce albuminuria at 2 mg U/l. Therefore a figure of 17 mg/l. U(nat) in urine would almost certainly produce albuminuria, although whether this would be permanently harmful is a more debatable question. Luessenhop *et al.*[5] state that the minimal injected dose necessary to produce catalasuria and

Incl 1

Table 1

Animal	Lethal dose* U(nat)	Equivalent in 60-kilo man
Rabbit	0.1 mg U/kg	6 mg
Guinea pig	0.3 mg U/kg	18 mg
Rat	1 mg U/kg	60 mg
Mouse	10–20 mg U/kg	600–1200 mg
Dog (subcutaneous "uranium nitrate")	about 2 mg U/kg	120 mg

* Expressed as lethal dose rather than LD_{50} since the dose-effect curve rises very steeply.

albuminuria in man is of the order of 0.1 mg uranium/kg body weight for hexavalent uranium. Thus for a 60-kilo man 6 mg in the body would be likely to [redacted]. This might be equivalent to an initial excretion of 3 mg uranium/l. urine.

Table 1 shows approximate [redacted] of uranyl nitrate hexa-hydrate solution administered [redacted] in five species of animals, and followed for up to 29 days.[4]

Luessenhop *et al.*[5] by extrapolation of experience gained from the Massachusetts Hospital series of cases consider that the injected lethal dose for man might be about [redacted] which is about the same level as for the rat. Therefore, [redacted]

From these sources of evidence 34 mg absorbed into the body in one incident would appear to be excessive. Therefore a 13-week dose all in one exposure must be ruled out on toxicity grounds. In man, the urinary excretion rate from a single dose of soluble uranium remains high for about 8 hr[3] and then starts to fall off fairly rapidly. It would seem reasonable therefore that 1 day's total exposure could be allowed as a single intake; this quantity is 2.1 mg in the air breathed (or to allow some free play 2.5 mg).

Radiation workers—inhaled insoluble uranium

For insoluble uranium the critical organ is considered to be the lung, based on radiation exposure rather than on toxic effect. Insoluble uranium in the lung is excreted very slowly through the kidneys;[7] therefore if it were certain that all the airborne uranium was insoluble, exposures should be able to be integrated over 13 weeks. However, it is difficult often to be sure that all the uranium is present in such form; moreover there might be considerable excretion in the urine even after 13 weeks had elapsed,[8] thus confusing the pattern of urine analysis during subsequent routine operations. Therefore, it might be wise not to make any exception of insoluble uranium unless in very well controlled circumstances. It may be worth noting that Patterson[8] describes two cases of human exposure to U_3O_8 in which urinary excretion after some days indicated a lung half-life of about 120 days, as postulated in the ICRP (1959) calculations for insoluble uranium.[11] Possibly the [redacted] of the uranium inhaled.

Population exposure—inhaled soluble uranium

It is suggested in paragraph 56 of ICRP (1959)[11] that, for exposure of special groups of the population, "the individual maximum permissible annual dose will not be exceeded from internal exposure of any single organ, if the release of radioactive material is planned on the basis of one-tenth of the maximum permissible concentration(MPC) in air or water as given for continuous occupational exposure (168-hour week)."

If it were allowable that integration of a uranium dose could take place over 1 year we have:

Occupational m.p.c.$_a$ U(nat) soluble (168-hr week) $= 3 \times 10^{-11}$ $\mu c/cm^3$
$= 90$ $\mu g/m^3$.

Therefore dividing by 10 for population exposure and integrating over 52 weeks, there would be produced in a single dose $\frac{90}{10} \times 20 \times 365$ $\mu g = 66$ mg inhaled (assuming 20 m^3 of air inhaled per day), or 16 mg in the blood of an adult, with correspondingly less in a child. This again would be very likely to produce albuminuria, especially in those with damaged kidneys.

[redacted] but within limits, a [redacted]

and thus differs from the radiation hazard which, for many of its effects, is cumulative. Also Hodge *et al.*[9] in discussing MAC's for uranium in air, based their arguments on experiments in which animals were exposed to steady levels of atmospheric uranium rather than to a series of larger doses spaced at intervals. Moreover, there seems to be no tendency to quote special public health m.p.c.'s for chemically toxic substances (except in the case of beryllium). Therefore it is suggested that for adults in a population, and for purposes of averaging only, the maximum single intake by the inhalation route should be the same as for the occupational situation, i.e. approximately 2.5 mg uranium. The maximum single intake for children would be lower by a factor ranging up to about 10 depending upon age and kidney size, but on the other hand minute volume figures for air breathed at different ages vary by a factor of the same order,[10] so that the appropriate concentrations in air would be likely to be about the same as for adults.

Population exposure—inhaled insoluble uranium

There is usually some difficulty in deciding whether uranium to which a population may be exposed is in the soluble or insoluble form; if, however, exposure was definitely proved to be due to insoluble material only, then the hazard would appear to be mainly of a radiological character, with the lung as the critical organ. In this case the averaging rules as enunciated by the ICRP would, of course, apply.

INGESTED URANIUM

Ingested uranium—occupational and population exposure

Similar calculations can be made for ingested uranium, e.g.

m.p.c.$_w$ U(nat) soluble or insoluble (168-hr week) $= 2 \times 10^{-4}$ $\mu c/cm^3$ (ICRP 1959)
$= 6 \times 10^{-4}$ g/cm^3.

Daily amount ingested at m.p.c.
$= 6 \times 10^{-4} \times 2200$ g (assuming water intake $= 2200$ cm^3/day)
$= 1.3$ g (occupational) or 0.13 g (population exposure).

52-week exposure (ingested)
$= 0.13 \times 365 \doteq 47$ g (population exposure).

This again would seem to be much too much if ingested in one dose. A human volunteer ingested 1 g of uranyl nitrate hexahydrate in 200 cm^3 water ($= 0.47$ g uranium).[11] He experienced rather violent vomiting, diarrhoea and slight albuminuria with a peak uranium output in urine at the rate of 8 mg U/l. (on two specimens of 30 ml). In the first 7 days he excreted in his urine 2.5 mg of uranium element. It was thought therefore that he may have absorbed about 1 per cent of the ingested dose, i.e. much greater than the 10^{-4} fraction estimated by ICRP (1959) and based on animal work.[1] More recent work by Fish *et al.*[12] on dogs given uranyl fluoride in water by mouth, showed that uptake into the bloodstream averaged 1.5 per cent of the rather high dose administered.

It seems that the 1959 occupational m.p.c. for ingestion might have been rather high and that the irritative effect of these comparatively large amounts or uranium on the gastrointestinal tract may have been underestimated.* The occupational m.p.c. for ingestion is however only of interest as a measure of the gravity of an accidental ingestion in a radiation worker.

The more important figure to establish is the population dose for ICRP Group B(c) which an individual may ingest at one time. Evidence is lacking, but it is suggested that approximately one-third of the dose found to be irritating to the gut in the above experiment might be allowable, i.e. 150 mg uranium (measured as the element). This would be equivalent to averaging the maximum permissible exposure over 2 days if only fluid intake (1200 cm^3/day) is contaminated, but would represent a shorter time than this if total water intake (2200 cm^3/day) is contaminated.*

Since children's kidneys are about one-tenth the size of an adult's, it would seem logical to reduce the above intake by one-tenth for environmental use.* The weight of both kidneys in a new born baby is 20–30 g, whilst the weight of both kidneys in adults is 260–360 g.[13] The fluid intake of a baby is about

* *ICRP Publication* 6 has tackled these problems by reducing factor f_w (fraction reaching organ of reference by ingestion) from 10^{-4} to 10^{-2}, as well as by laying down maximum limits for inhalation and ingestion.

a fifth of that of an adult,[13] so that this factor partially compensates for the smaller size of a baby's kidneys relative to those of an adult.

PLANNED EMERGENCY EXPOSURES OF EMPLOYEES

It is suggested that 10 mg of soluble natural uranium inhaled over a short period would, on ICRP principles, lead to a total dose of 2.5 mg in the bloodstream (i.e. absorbed dose). This is somewhat less than the 0.1 mg/kg injected dose which LUESSENHOP *et al.*[5] mention as the nephrotoxic dose for man. Therefore a figure of 10 mg natural uranium in the total air breathed over a period might be considered as a reasonable "planned emergency exposure" in the ICRP sense. In effect this would be equivalent to administering nearly 5 days' dose at one time, but this dose would be subject to the rules of other planned emergency exposures.

ENRICHED URANIUM

For enriched uranium the principles discussed above would apply for the toxic effect, but the radiological effect on bone or kidney could be integrated in the ICRP way. The simplest solution is to express maximum single intakes of uranium in units of weight as above, and consider that these apply to any given enrichment of uranium.

Acknowledgment—I am grateful to a number of colleagues in the United Kingdom Atomic Energy Authority and to Dr. J. F. LOUTIT of the Medical Research Council, who have criticised an earlier draft of this paper.

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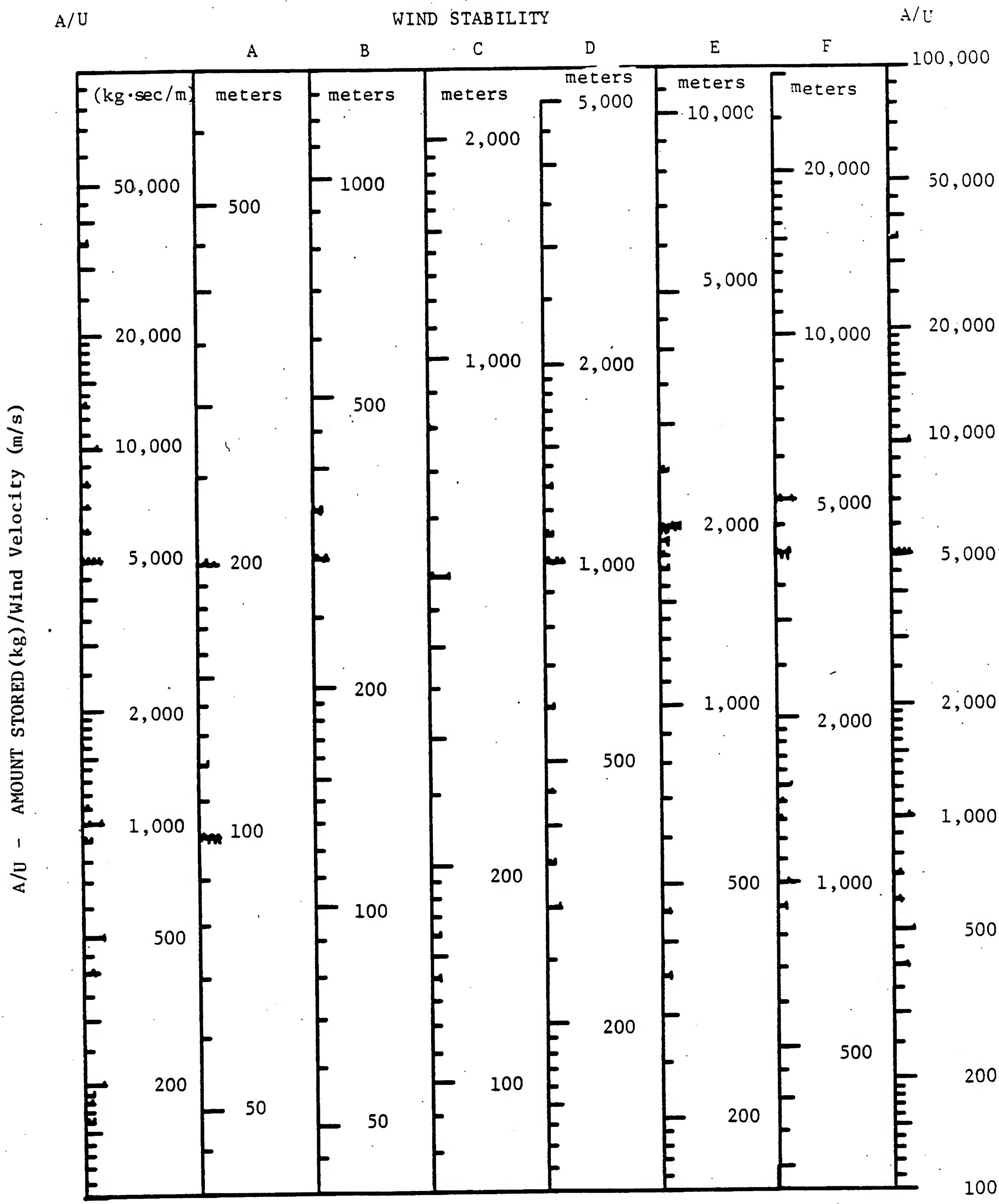
CONTROL BOUNDARY FOR FIRES

Amount Stored per unit wind velocity (A/U) kg sec/m	PASQUILL'S STABILITY CATEGORIES A	B	C	D	E	F
	DISTANCES					
	km	km	km	km	km	km
100.	0.04	0.04	0.07	0.11	0.15	0.27
200.	0.05	0.06	0.09	0.16	0.24	0.44
500.	0.76	0.1	0.15	0.27	0.42	0.8
800.	0.94	0.13	0.2	0.36	0.56	1.1
1000.	0.1	0.14	0.22	0.4	0.64	1.3
2000.	0.14	0.19	0.31	0.56	1.	2.1
5000.	0.2	0.31	0.5	1.	1.9	4.
8000.	0.25	0.4	0.66	1.3	2.4	5.6
10000.	0.27	0.44	0.74	1.5	2.7	6.4
20000.	0.36	0.62	1.05	2.3	4.4	10.
50000.	0.52	1.	1.7	3.8	7.6	19.
80000.	0.64	1.25	2.2	5.	10.	27.
100000.	0.7	1.4	2.5	5.6	12.	31.



A/U
WIND STABILITY
A/U
A
B
C
D
E
F
(kg·sec/m)
meters
meters
meters
meters
meters
meters
100,000
50,000
20,000
10,000
5,000
2,000
1,000
500
200
100
A/U - AMOUNT STORED (kg)/Wind Velocity (m/s)
500
200
100
50
1000
500
200
100
50
2,000
1,000
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200
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1,000
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Inc. 3

DEPARTMENT OF THE ARMY
US ARMY MOBILITY EQUIPMENT RESEARCH & DEVELOPMENT COMMAND
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still Valid - Mar 1984

DRDME- VR

7 MAR 1979

DISPERSAL OF URANIUM DURING A FIRE

Report No.: 08661RJAY-4 (Revised)

Authority: A928941FK11

1. Purpose. The purpose of this report is to determine the exclusion control boundaries for fires involving depleted uranium ammunition in transit or in storage. Radiation and chemical toxicity are considered in establishing the criteria for the control boundaries. This report is prepared in the absence of experimental data on the amount of uranium released to the atmosphere during a fire. This lack of data leads to the conservative assumption that all of the uranium will be aerosolized in a soluble form.

2. Background.

a. Uranium, as a heavy metal, is an ideal projectile for ammunition. The advantages are offset by some disadvantages associated with the controllable hazards of manufacturing, transporting and storing. The hazards to workers who process uranium have been identified in numerous studies. Using proper precautions these workers can be protected from the exposure to the dust from the processing procedures in a continuous day-to-day environment.

b. Natural uranium contains three primary isotopes: U-238, U-235 and U-234. All of the isotopes are radioactive. The limit set for the exposure of radiation workers is based on the concentration of uranium in the air that will damage the kidney, the critical organ. For a worker in a concentration of uranium dust, the time average value for the concentration over a 40 hour work week is set as 0.2 mg/m**3. (10CFR20) The maximum excursion is set at a factor of 3 or 0.6 mg/m**3. (Sax)

c. An accident or fire that occurs during transport or storage presents some special problems. Not only the people in the immediate vicinity (emergency and fire fighting personnel) but also people at distances downwind from the fire are faced with potential over exposure to airborne uranium dust. This dispersal of uranium can expose all age groups in the general public. The exposure limits that have been established for the working population are not directly applicable to this group. The standards were written on the basis of continuous exposure where the concentration of uranium in the body will reach an equilibrium level. The general population will be exposed to a single exposure and there will be no significant uranium concentration in the body at the time of exposure.

3. Population Differences. Different segments of the population will have different maximum uranium intakes before undesirable effects begin to occur. These population differences are related to the mass of the kidneys, where the limit is established at three microgram of uranium per gram of tissue. This variation of total intake does not necessarily imply that there will be vastly different concentrations for the individuals to reach their limits. The factors that influence the concentration are the individual limit for intake, the ventilation rate and the time for the exposure. Since we are dealing with an acute exposure, there will be only minor changes in the effects whether the exposure occurs in one hour or six hours.

4. Parameters of Uranium Release During Fire. The release of uranium is assumed to be a point source at ground level. This assumption will result in calculating concentrations that are higher than will occur in practice. This is a conservative approach to the problem. (NUREG-0170) All of the uranium will be aerosolized in a soluble form.

5. Approach for Limit Calculation. Two approaches will be taken for the acute exposure limit. The first will be made on the basis of the standard for continuous exposure and the results calculated for an acute exposure. The second is based on a maximum concentration of uranium in the kidneys. These two approaches yield similar results and provide a basis for selecting a concentration time factor that is used in calculating the control boundaries.

6. Derived Uranium Concentration Limit (Acute Exposure). The established limit for the concentration of uranium in air, as well as the accepted excursion factor, was based on continuous exposure. When one is dealing with an acute exposure, such as a fire, the exposed individuals will have no initial body burden and the maximum permissible uranium concentration in air can be higher without the kidneys becoming overburdened. The following derivation gives a method to estimate concentration limits for acute exposure.

a. Under continuous exposure, the amount of uranium in the kidneys will be constant and the amount excreted daily will equal the amount taken into the body. This may be expressed as:

L*N= r*V*C

where:

L= ln(2)/15, the decay constant based on a biological half-life of 15 days.

N= amount of uranium in the kidneys.

r= fraction absorbed into the body.

V= ventilation rate (1.25 m**3/hr).

C= concentration limit (0.2 mg/m**3).

b. During an accidental release, the total amount of uranium in the kidneys will not be greater than that absorbed into the body. If the total body absorption is limited to that permissible in the kidneys under continuous exposure conditions, then the following relation holds:

N=r*V*C/L= r*V*(t/8)*D

where:

t= number of hours over which exposure occurs.

D= derived concentration limit.

This may be solved for the derived concentration time limit and the result is:

D*t=8*C/L

Substituting for C and L, the concentration time factor is found to be 34.6 mg-hour/m**3.

7. The second approach to calculating the control limit uses the maximum permissible concentration of uranium in kidney tissue. According to WASH 1251, this is three microgram per gram of tissue. For an adult with a kidney mass of 300 grams, this gives a total of 900 microgram of uranium in the kidneys. ICRP 2 give 0.028 as the fraction of the inhaled uranium that is deposited in the kidneys.

a. The following equation describes the limiting condition.

0.028*V*C*T=0.003*M or C*T=0.003*M/(0.028*V)

where:

V= ventilation rate (m**3/hr).

C= concentration (mg/m**3).

M= mass (g).

T= time (hours).

b. The results of the calculations for various age groups are given in the following table. Two sets of data are reported that reflect the different ventilation rates that are given in NUREG 0172 and the Radiological Health Handbook.

Group	Kidney mass g	Ventilation rate m**3/hour	C*t mg*hr/m**3
NUREG 0172			
Infant	55	.233	25.24
Child	100	.292	36.66
Teen	210	.562	39.97
Adult	300	.833	38.57
Radiological Health Handbook			
Infant (1y)	55	.195	30.09
Child (10y)	175	.616	30.43
Adult (avg)	300	.95	33.83
Adult (work)	300	1.25	25.71

c. The mass of the kidney for the child in the table using the data for breathing from the Radiological Health Handbook is based on the data from Spector by averaging the masses for the 9-10 and 10-11 years. This is higher than that used as the average of the 1 to 10 year (see NUREG 0172). The transfer from the blood to the kidneys is 0.11.

8. Selection of a Concentration Time Limit. Both of the above approaches yield values that are always greater than 25 mg-hour/m**3. This is to be compared to 8 mg-hour/m**3, the weekly limit for a production worker. It is instructive to evaluate the implications of the use of 25 mg-hour/m**3 in terms of estimated effects of acute exposures on the body functions.

9. A single intake into the blood stream may produce death if the amount exceeds 1 mg/kg of body weight. (Luessenhop) (Wright) The concentration time factor of 25 can be used to calculate the body intake by remembering that 25% of the soluble uranium that is inhaled will be absorbed and by using the respiration rate for the particular age group. This can then be compared to the body weight.

Group	Respiration Rate m**3/hr	Absorbed Uranium mg	Body Mass kg	Ratio mg/kg
Infant	.233	1.456	10.7	.136
Child	.292	1.825	21	.086

Group	Respiration Rate m**3/hr	Absorbed Uranium mg	Body Mass kg	Ratio mg/kg
Teen	.562	3.512	45	.078
Adult	.833	5.206	70	.074
Adult (work)	1.25	7.812	70	.111

10. This evaluation of the use of the concentration time factor as 25 mg-hour/m**3 indicates that the acceptance of this value as a limit is not unreasonable. The body burden is less than 0.15 mg/kg which is less than 15% of the limit that Luessenhop, et al, set for an acute exposure to possibly result in the death of an individual. For the balance of the report, a concentration time factor of 25 mg-hour/m**3 will be used for the control limit.

11. Plume Depletion.

a. The plume depletion is calculated by the equation:

R=0.9-0.05862*ln(x)-0.01037*(ln(x))**2. For $x > 0.1$

R=1 For $x \leq 0.1$

where:

R= fraction remaining in the plume.

x= distance of plume travel in kilometers.

b. This equation approximates the graph of Figure 2, NRC Regulatory Guide 1.111 and is applicable for all atmospheric conditions when the releases are at ground-level. Plume depletion is dependent on many different factors. Gudiksen, et al, studied the depletion rates for plutonium dioxide releases over different types of terrains. The fraction remaining in the plume, as calculated using the above equation, will be larger (hence, more conservative) than those reported by Gudiksen.

12. Uranium Concentration in the Plume. The uranium concentration in the plume was calculated using the constant mean wind model (equation 3) of NRC Regulatory Guide 1.111. It is assumed that the wind speed, direction and the source strength will remain constant and that the release is at ground-level. The concentration time factor can be expressed as:

C*T=2.032*Q*R*T/[X*U*S(X)]

where:

C= concentration in the plume - g/m**3.

Q= source strength - kg/s.

R= plume depletion factor.

T= time - hours.

X= distance from the source - km.

U= wind velocity - m/s.

S(x)= vertical plume spread based on distance, X, and the atmospheric stability class - m.

2.032= factor that accounts for the 22.5 degree sector that is considered.

13. Scenario of an Accident. A fire occurs in an igloo magazine where depleted uranium ammunition is stored or in a transport vehicle carrying the ammunition. The stored uranium is released to the atmosphere in respirable sizes. Three atmospheric stability classes are considered: (1) Stability classification "B" or moderately unstable. (2) Stability classification "D" or neutral. (3) Stability classification "F" or moderately stable. The wind direction is assumed to remain constant; i.e., within the same 22.5 degree sector, during the release. Several wind speeds (1, 2, 5, 8, and 10 meters per second) are used to calculate

the distances where various uranium concentrations in air will be reached. The air concentrations of 25 mg-hour/m**3, 8 mg-hour/m**3, and 2.5 mg-hour/m**3 will be used to indicate various levels of control. These three levels represent a maximum acute exposure, the maximum weekly exposure for workers in uranium production and a value of 0.1 times the maximum exposure.

14. Results. The results of the calculations are shown in Tables 1-3. Each table gives the distances for the plume concentration time factor to decrease to the specific level. The iterative procedure was stopped when the calculated distance was within one percent. Some general comments are: (1) Smaller areas will need to be controlled when the wind velocity is higher. (2) The more unstable the atmosphere, the more rapidly the plume disperses. (3) The potential area for control can be reduced by keeping smaller quantities of uranium in any one area.

15. Discussion.

a. The uranium concentration in the air surrounding the fire will exceed the concentration limit calculated for an acute exposure. Emergency personnel working to control the incident are required to take protective measures to avoid inhaling the dust. Self-contained breathing unit will probably be most effective in this area.

b. The people in downwind positions should be evacuated if they are in regions where the concentration time factor is expected to exceed the acute exposure limit of 25 mg-hour/m**3. Those further downwind can be advised to remain indoors during the passage of the plume. This latter measure will give an additional safety factor and reduce the body burden in the exposed population.

c. This study indicates the general scope of the problem associated with DU ammunition during a fire. Specific recommendations for a site are dependent upon a number of factors which are site dependent. This study does not provide a procedure that will permit an easy evaluation of a site based on the varying factors.

d. As an example: Consider a storage location where the facility has control over the area out to a distance of 3 km. Using the results for the "F" stability class, the maximum amount in storage is 5000 kg of uranium. If one has evidence that the prevailing winds and stability class are such that the wind speed is always greater than 4 m/s and a stability class is "B", then the maximum amount in storage is over 400000 kg (see table for class "B" stability). This example is an illustration of how the tables may be used with site-specific information.

e. Figures 1 through 4 show in graphical form the information contained in the tables. Figure 1 permits a visual comparison of the changes in control boundary with changes in the stability classes. Figures 2 through 4 will be used to determine the location of control boundaries for specific storage quantities, or alternatively, the limits of storage based on the known boundaries which are controlled around a storage site.

f. This study has been based on the release of the uranium as a soluble compound. In the following table, the radiological implications for insoluble compounds is given for different body organs. (Hoenes) The table gives the dose commitment in mrem for 50 years to an individual exposed at the control boundary of 25 mg-hour/m**3.

Group	Lung	Total Body	Bone	Kidney
Infant	642	6.9	100	19.8
Child	402	6.3	107	17.1
Teen	398	4.1	68.3	15.6
Adult	343	4.2	71.5	15.6
Adult (work)	515	6.4	107	24.4

g. The lungs will receive the largest dose commitment which is over 500 mrem per incident for the infant and the working adult. These are dose commitments for 50 years from a single incident, but the dose is effectively delivered to the lungs during the first two years. The infant at the control boundary will receive 563 mrem during the first year from the single incident.

16. Adopted Conventions. The following symbolic conventions are used.

a. * = multiplication.

b. / = division.

c. ** = exponent.

d. ln = natural logarithm.

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7 Incl
as

SUBMITTED BY: ROBERT C. McMILLAN
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FORWARDED BY: EMIL J. YORK
Chief, Material Technology Laboratory

Assume that air sample results have shown that during a fire a group of workers have been exposed to a cloud of depleted uranium oxides. Airborne concentrations appear to have exceeded 100 times MPC and workers were present in this atmosphere between 10 and 45 minutes. Decide what actions you need to take to evaluate the workers dose and prepare a presentation program to the workers explaining the hazards of uranium, the fate of the uranium that has entered the workers' bodies and the evaluations that will be performed.

520 MPC-hrs/qtr. Allowed

minimal total exposure over quarter

may have to

1 survey people

2. control area

3. environmental

4. rumor

5. decontamination

6. waste control

1. nasal swipes

2. urinalysis 24 hr / periodic 1 every [illegible] 1-wk

3. whole body count

4. lung count

5. fecal

Assume that air sample results have shown that during a fire a group of workers have been exposed to a cloud of depleted uranium oxides. Airborne concentrations appear to have exceeded 100 times MPC and workers were present in this atmosphere between 10 and 45 minutes. Decide what actions you need to take to evaluate the workers dose and prepare a presentation program to the workers explaining the hazards of uranium, the fate of the uranium that has entered the workers' bodies and the evaluations that will be performed.

Assuming you are RSO at a facility that converts DERBY into metallic uranium. Describe your response to a biweekly bioassay sample from a worker that contains 130 μg/l uranium by fluorometric analysis. Assume the high reading was discovered 3 days after the sample was collected. Would your response change if a worker with a similar job on a different shift also showed a similar high result. If so, how would it change?

Recall

Remove

130 μg/l - must notify NRC

Reg Guide 2.2 - uranium mill workers

A fire in a building where uranium is machined has spread to the duct work and resulted in considerable damage. Describe the assessment actions you, as the radiation safety officer in charge of the facility, would take once the fire is extinguished. Consider especially the following: (1) The fire fighters and their equipment; (2) Potential environmental releases; (3) A radiation safety program for facility entry and damage/material inventory; (4) The notifications that might be required presuming that some depleted uranium had burned in the fire.

HEALTH PHYSICS ASPECTS OF DEPLETED URANIUM
CLASS PROTOCOL

Reference Text	Fundamentals of Health Physics for the Radiation Protection Officer
Questions:	The only dumb questions are those that go unanswered. Please ask. The others are probably waiting for someone else to ask first.
Experience:	You are each experts in your area. You may have valuable information that others can use. Please share.
Homework:	Reading assignments and some problems will be given.
Examinations	A pre-course test will be given with a 30 minute time allotted. A final examination will be given with a two hour time allotted.
Attendance	Your signature on the attendance form each day of the course is required to receive an attendance certificate.

HEALTH PHYSICS ASPECTS OF DEPLETED URANIUM
SCHEDULE

Monday, March 5, 1984

8:00 a.m.		Introduction
		Pre-Course Test
	1.	Characteristics of Depleted Uranium
	2.	Radiation Physics
		BREAK
	3.	Radiation Biology and Toxicology
	4.	Purpose of Radiation Safety Program
12:00 noon		LUNCH
1:00 p.m.	5.	Radiological Surveillance Program
	6.	History of Depleted Uranium Production
	7.	Military Uses of Depleted Uranium
		BREAK
	8.	Uranium Processing to Green Salt
	9.	Uranium Processing, Green Salt to Metal

Tuesday, March 6, 1984

8:00 a.m.	10.	Uranium Metal Processing
12:00 noon		LUNCH
1:00 p.m.	11.	Waste Management
	12.	Dosimetry and Instrumentation
		Workshop Instrumentation

Wednesday, March 7, 1984

8:00 a.m.	12A.	Fire Hazards of DU Munitions
	13.	Demilitarization of DU Ammunition
12:00 noon		LUNCH
1:00	14.	DU Munitions Storage and Transport Munitions Quality Control

Thursday, March 8, 1984

8:00 a.m.	16.	Hard Impact Testing
	17.	Radiation Safety for Test Operations
12:00 noon		LUNCH
1:00 p.m.	18.	Recovery and Restoration Problem Solving Workshop

Friday, March 9, 1984

8:00 a.m.	19.	Aerosol Sampling
	20.	Environmental Monitoring
		BREAK
		FINAL EXAMINATION
12:00		CLOSE

HEALTH PHYSICS ASPECTS OF DEPLETED URANIUM

OUTLINE

		Reference Text
1.	Characteristics of Depleted Uranium	
	Isotopic	
	Physical Properties	
	Chemical Properties	
	Nuclear Properties	
2.	Radiation Physics	Chapter 1, pages 5-33
	Natural Radiation	pages 49-53
	Manmade Radiation	
	Atomic Structure	
	Isotopes	
	Radioactive Decay	
	Properties of Ionizing Radiation	
	Radiation Quantities and Units	
	Types of Radiation Exposure	
3.	Radiation Biology and Toxicology	Chapters 1, pages 31-41
	Radionuclide Pathways Into the Body	Chapter 5, pages 3-37
	Radionuclide Transport Within the Body	Chapter 7, pages 6-13
	Maximum Permissible Concentrations	
	Threshold Limit Value	

		Reference Text
	Bioassay	
	Biological Effects of Radiation	
	Acute and Chronic Exposure	
4.	Purpose of Radiation Safety Program	Chapter 3, pages 3-26
	ALARA	
	External Exposure	Chapter 6, pages 3-26
	Internal Exposure	Chapter 8, pages 15-34
	Contamination Control	
	Predicting and Controlling Radiological Hazards	
5.	Radiological Surveillance Program	Chapter 4, pages 5-35
	Program Administration	
	Radiological Measurements	
	Protective Measures	
6.	History of Depleted Uranium Production	
7.	Military Uses of Depleted Uranium	
	Uses of Depleted Uranium	
	Advantages of Depleted Uranium	
	Disadvantages of Depleted Uranium	
8.	Uranium Processing to Green Salt	
	Mining	
	Milling	

		Reference Text
	Conversion	
9.	Uranium Processing, Green Salt to Metal	
	Orange Salt	
	Green Salt	
	Metal	
	Prurification	
10.	Uranium Metal Processing	
	Conversion of DU Derby to Components	
	Conversion of DU Derby to Rod	
	Conversion of DU Rod to Penetrator	
	Hazards Associated with Mechanical Process	
	Hazards Associated with Machining/Lathing	
11.	Waste Management	Chapter 10, pages 3-14
12.	Dosimetry and Instrumentation	Chapter 2, pages 5-52
	Personnel DU Dosimetry Program	
	Personnel DU Dosimetry Types	
	Factors in Accurate Dose Assignment	
	Radiation Detector Instruments	
	Instrumentation Workshop	
12A.	Fire Hazards of DU Monitors	
	Heat Test (XM774)	

		Reference Text
	Heat Test (XM829)	
	Conclusions	
	Los Alamos Heat Test	
13.	Demilitarization of DU Ammunition	
14.	DU Munitions Storage and Transport	Chapter 9, pages 5-54
15.	Munitions Quality Control	Chapter 14, pages 3-16
	DOA Supplier Surveys	Chapter 15, pages 5-42
	Pre-Award and Post-Award Surveys	
	Health Physics Programs	
	Fire Protection Programs	
16.	Hard Impact Testing	
	Surface Contamination	
	Airborne Contamination	
17.	Radiation Safety for Test Operations	
18.	Recovery and Restoration	Chapter 7, pages 14-16
	Property	pages 31-44
	Equipment	
	Approvals	

		Reference Text
19.	Aerosol Sampling	Chapter 4, pages 21-23
	Respirable Particulates	Chapter 5, page 6
	Routine Air Sampling	Chapter 13, pages 5-50
	Selection of Sampling Locations and Equipment	
	Sampling Frequency	
	Records	
20.	Environmental Monitoring	Chapter 4, page 30
	Relationship to Radiation Safety Program	Chapter 3, page 8
	Elements of the Environmental Monitoring Program	
	Records Requirements	

CHARACTERISTICS OF DU

ISOTOPIC CONTENT (WT%)

ISOTOPE	NATURAL URANIUM	ENRICHED U	DEPLETED U
238U	99.2739 ± 0.0007	97.01	99.75
235U	0.7204 ± 0.0007	2.96	0.25
234U	0.0057 ± 0.0002	0.03	0.0005

PHYSICAL PROPERTIES

DENSITY	19.214 g/cm3 (X-RAY DENSITY, ALPHA URANIUM, 20° C)
	18.78 g/cm3 (AVERAGE DENSITY, BETA QUENCHED FUEL RODS, 18° C)
	19.05 ± 0.02 g/cm3 (HIGH-PURITY, DIRECTIONALLY SOLIDIFIED, 25° C)

MELTING POINT

THEORETICAL 1132° C   LUSTROUS METAL RESEMBLING IRON DUCTILE AND MALLEABLE

$$\left(7\times10^{-11}\ \mu C/\cancel{ml}\right)\left(\frac{g}{3.6\times10^{-7}\ Ci}\right)\left(\frac{10^{-6}\ Ci}{\mu Ci}\right)\left(\frac{10^{6}\ \cancel{ml}}{m^3}\right)\left(\frac{mg}{10^{-3}\ g}\right) = \frac{7\times10^{-11}}{3.6\times10^{-7}\times10^{-3}}\ \frac{mg}{m^3} = \frac{7\times10^{-11}}{3.6\times10^{-10}} = 0.19\ mg/m^3$$

activity

mass terms

CRYSTALINE FORMS

ALPHA	TO 660°C
BETA	660°C TO 770°C
GAMMA	770°C TO MELTING POINT
DU PENETRATORS	U dep -0.75 WT% Ti

CHEMICAL PROPERTIES

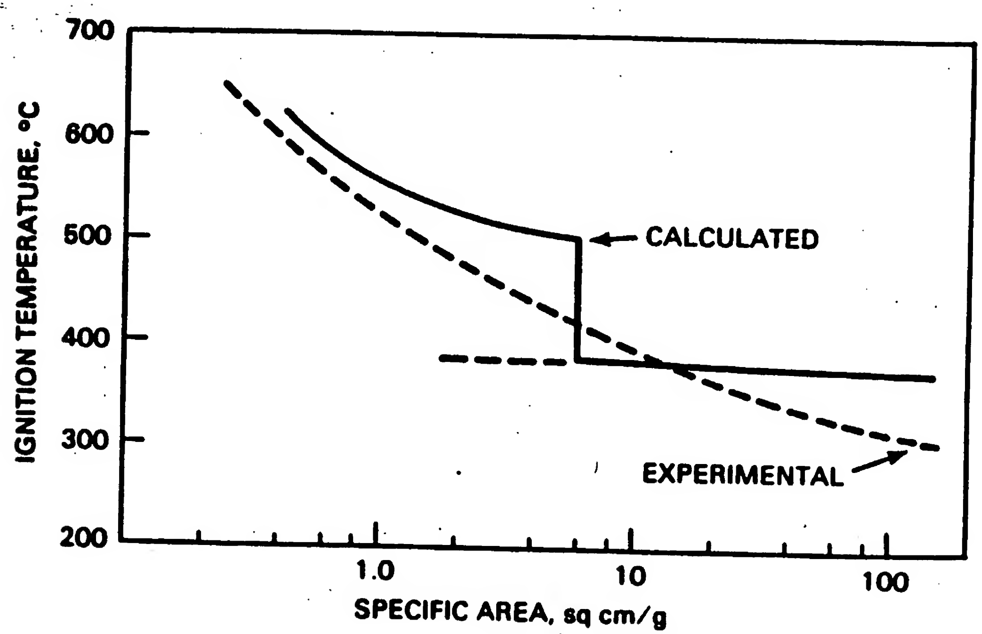
HIGHLY REACTIVE

PYROPHORIC

COMPLEX CHEMISTRY

COMPOUND	CHEMICAL FORMULA
AMMONIUM DIURANATE (ADU)	$(NH_4)_2U_2O_7$
URANIUM HEXAFLOURIDE	UF_6
URANIUM TRIOXIDE orange salt.	UO_3
URANYL ACETATE	$UO_2(C_2H_3O_2)_2$
URANYL CHLORIDE	UO_2Cl_2
URANYL FLUORIDE	UO_2F_2
URANYL NITRATE	$UO_2(NO_3)_2$
URANYL SULFATE	UO_2SO_4
URANIUM DIOXIDE	UO_2
URANIUM TETROXIDE green salt	UO_4
URANIUM ALUMINIDE	UAl_x
URANIUM CARBIDE	UC_2
URANIUM DIOXIDE (HIGH-FIRED)	UO_2
URANIUM OXIDE - combustion by-product	U_3O_8
URANIUM TETRAFLUORIDE	UF_4
URANIUM-ZIRCONIUM ALLOY	UZR

PYROPHORICITY



DEPENDENCE OF URANIUM IGNITION ON SPECIFIC AREA

(L. BAKER, JR., J. G. SCHNIZLEIN AND J. D. BINGLE 1966)

NUCLEAR PROPERTIES

HEAVY ATOMS

uranium will undergo spontaneous fission! i.e. it will emit a neutron

6.5×10^{15} years

very few - no concern

RADIOACTIVE

PRIMARILY ALPHA RADIATION FROM PURE URANIUM

TWO DECAY SERIES

Uranium Series (4n + 2)*

Nuclide	Historical name	Half-life	Major radiation energies (MeV) and intensities† α	β	γ
$^{238}_{92}U$	Uranium I	4.51×10^{9}y	4.15 (25%) 4.20 (75%)	---	---
$^{234}_{90}Th$	Uranium X_1	24.1d	---	0.103 (21%) 0.193 (79%)	0.063c‡ (3.5%) 0.093c (4%)
$^{234}_{91}Pa^{m}$ (99.87% / 0.13%)	Uranium X_2	1.17m	---	2.29 (98%)	0.765 (0.30%) 1.001 (0.60%)
$^{234}_{91}Pa$	Uranium Z	6.75h	---	0.53 (66%) 1.13 (13%)	0.100 (50%) 0.70 (24%) 0.90 (70%)
$^{234}_{92}U$	Uranium II	2.47×10^{5}y	4.72 (28%) 4.77 (72%)	---	0.053 (0.2%)
$^{230}_{90}Th$	Ionium	8.0×10^{4}y	4.62 (24%) 4.68 (76%)	---	0.068 (0.6%) 0.142 (0.07%)
$^{226}_{88}Ra$	Radium	1602y	4.60 (6%) 4.78 (95%)	---	0.186 (4%)
$^{222}_{86}Rn$	Emanation Radon (Rn)	3.823d	5.49 (100%)	---	0.510 (0.07%)
$^{218}_{84}Po$ (99.98% / 0.02%)	Radium A	3.05m	6.00 (~100%)	0.33 (~0.019%)	---
$^{214}_{82}Pb$	Radium B	26.8m	---	0.65 (50%) 0.71 (40%) 0.98 (6%)	0.295 (19%) 0.352 (36%)
$^{218}_{85}At$	Astatine	~2s	6.65 (6%) 6.70 (94%)	? (~0.1%)	---
$^{214}_{83}Bi$ (99.98% / 0.02%)	Radium C	19.7m	5.45 (0.012%) 5.51 (0.008%)	1.0 (23%) 1.51 (40%) 3.26 (19%)	0.609 (47%) 1.120 (17%) 1.764 (17%)
$^{214}_{84}Po$	Radium C'	164μs	7.69 (100%)	---	0.799 (0.014%)
$^{210}_{81}Tl$	Radium C''	1.3m	---	1.3 (25%) 1.9 (56%) 2.3 (19%)	0.296 (80%) 0.795 (100%) 1.31 (21%)
$^{210}_{82}Pb$	Radium D	21y	3.72 (.000002%)	0.016 (85%) 0.061 (15%)	0.047 (4%)
$^{210}_{83}Bi$ (~100% / .00013%)	Radium E	5.01d	4.65 (.00007%) 4.69 (.00005%)	1.161 (~100%)	---
$^{210}_{84}Po$	Radium F	138.4d	5.305 (100%)	---	0.803 (0.0011%)
$^{206}_{81}Tl$	Radium E''	4.19m	---	1.571 (100%)	---
$^{206}_{82}Pb$	Radium G	Stable	---	---	---

*This expression describes the mass number of any member in this series, where n is an integer.
Example: $^{206}_{82}Pb$ (4n + 2)......4(51) + 2 = 206

†Intensities refer to percentage of disintegrations of the nuclide itself, not to original parent of series.

‡Complex energy peak which would be incompletely resolved by instruments of moderately low resolving power such as scintillators.

Data taken from: Table of Isotopes and USNRDL-TR-802.

Actinium Series (4n + 3)*

Nuclide	Historical name	Half-life	Major radiation energies (MeV) and intensities† α	β	γ
$^{235}_{92}U$	Actinouranium	7.1 x10^{8}y	4.37 (18%) 4.40 (57%) 4.58c‡ (8%)	---	0.143 (11%) 0.185 (54%) 0.204 (5%)
$^{231}_{90}Th$	Uranium Y	25.5h	---	0.140 (45%) 0.220 (15%) 0.305 (40%)	0.026 (2%) 0.084c (10%)
$^{231}_{91}Pa$	Protoactinium	3.25x10^{4}y	4.95 (22%) 5.01 (24%) 5.02 (23%)	---	0.027 (6%) 0.29c (6%)
$^{227}_{89}Ac$ (98.6% → $^{227}_{90}Th$; 1.4% → $^{223}_{87}Fr$)	Actinium	21.6y	4.86c (0.18%) 4.95c (1.2%)	0.043 (~99%)	0.070 (0.08%)
$^{227}_{90}Th$	Radioactinium	18.2d	5.76 (21%) 5.98 (24%) 6.04 (23%)	---	0.050 (8%) 0.237c (15%) 0.31c (8%)
$^{223}_{87}Fr$	Actinium K	22m	5.44 (~0.005%)	1.15 (~100%)	0.050 (40%) 0.080 (13%) 0.234 (4%)
$^{223}_{88}Ra$	Actinium X	11.43d	5.61 (26%) 5.71 (54%) 5.75 (9%)	---	0.149c (10%) 0.270 (10%) 0.33c (6%)
$^{219}_{86}Rn$	Emanation Actinon (An)	4.0s	6.42 (8%) 6.55 (11%) 6.82 (81%)	---	0.272 (9%) 0.401 (5%)
$^{215}_{84}Po$ (~100% → $^{211}_{82}Pb$; .00023% → $^{215}_{85}At$)	Actinium A	1.78ms	7.38 (~100%)	0.74 (~.00023%)	---
$^{211}_{82}Pb$	Actinium B	36.1m	---	0.29 (1.4%) 0.56 (9.4%) 1.39 (87.5%)	0.405 (3.4%) 0.427 (1.8%) 0.832 (3.4%)
$^{215}_{85}At$	Astatine	~0.1ms	8.01 (~100%)	---	---
$^{211}_{83}Bi$ (0.28% → $^{211}_{84}Po$; 99.7% → $^{207}_{81}Tl$)	Actinium C	2.15m	6.28 (16%) 6.62 (84%)	0.60 (0.28%)	0.351 (14%)
$^{211}_{84}Po$	Actinium C'	0.52s	7.45 (99%)	---	0.570 (0.5%) 0.90 (0.5%)
$^{207}_{81}Tl$	Actinium C"	4.79m	---	1.44 (99.8%)	0.897 (0.16%)
$^{207}_{82}Pb$	Actinium D	Stable	---	---	---

*This expression [illegible] mass number of any member in this series, where n is an integer. [illegible] (4n + 3)......4(51) + 3 = 207

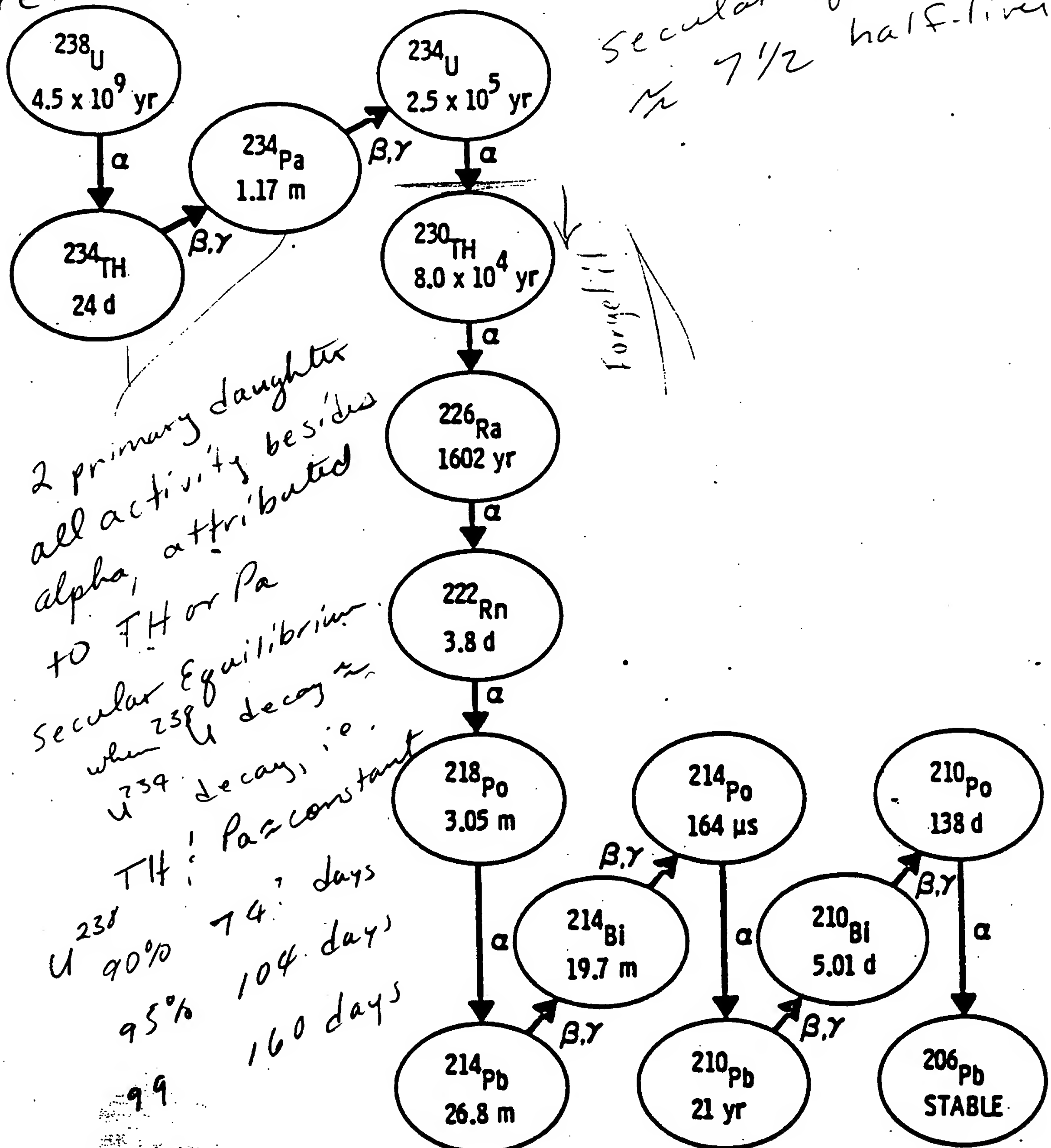
†Intensities [illegible] disintegrations of the nuclide itself, not to original parent of series.

‡Complex energy [illegible] incompletely resolved by instruments of moderately low resolving power such as scintillators.

Data taken from: Table of Isotopes and USNRDL-TR-802.

at manufacturing ... daughter products have (95%) been removed. But, they will reform over the next 7.5 half lives.

Secular Equilibrium ~ 7 1/2 half-lives



forget!!

2 primary daughter
all activity besides alpha, attributed to TH or Pa

Secular Equilibrium when 238U decay ≈ U234 decay, i.e. TH : Pa ≈ constant

U^{238} 90%	74	days
95%	104	days
99	160	days

URANIUM-238 DECAY SERIES

BETA SURFACE DOSE RATES FROM EQUILIBRIUM THICKNESS OF URANIUM METAL AND COMPOUNDS

SOURCE	SURFACE DOSE RATE* (mrad/hr)
^{NAT}U SLAB	233
UO_2	207
UF_4	179
$UO_2(NO_3)_3 6H_2O$	111
UO_3	204
U_3O_3	203
UO_2F_2	176
$NA_2U_2O_7$	167

7 mg/cm² dense of dead skin.

* BETA SURFACE DOSE RATE IN AIR THROUGH A POLYSTYRENE FILTER 7 mg/cm 2 THICK. (REFERENCES: KINSMAN, 1954; HEALY, 1970).

RADIATION PHYSICS

NATURAL RADIATION

higher @ altitude

COSMIC 75 – 40 mRem/hr ≈ Florida

EARTHS CRUST mRem/hr ≈ Florida
uranium primarily

INTERNAL

RADIATION PHYSICS

ESTIMATED TOTAL ANNUAL AVERAGE WHOLE-BODY DOSES FROM NATURAL RADIATION IN THE UNITED STATES (mrem/person)

SOURCE	ANNUAL DOSES
COSMIC RAYS	45
TERRESTRIAL RADIATION	
EXTERNAL	60
INTERNAL	25
TOTAL	130

Denver ≈ 250

RADIATION PHYSICS

RADIONUCLIDES OF SIGNIFICANCE CONTRIBUTING TO INTERNAL DOSE

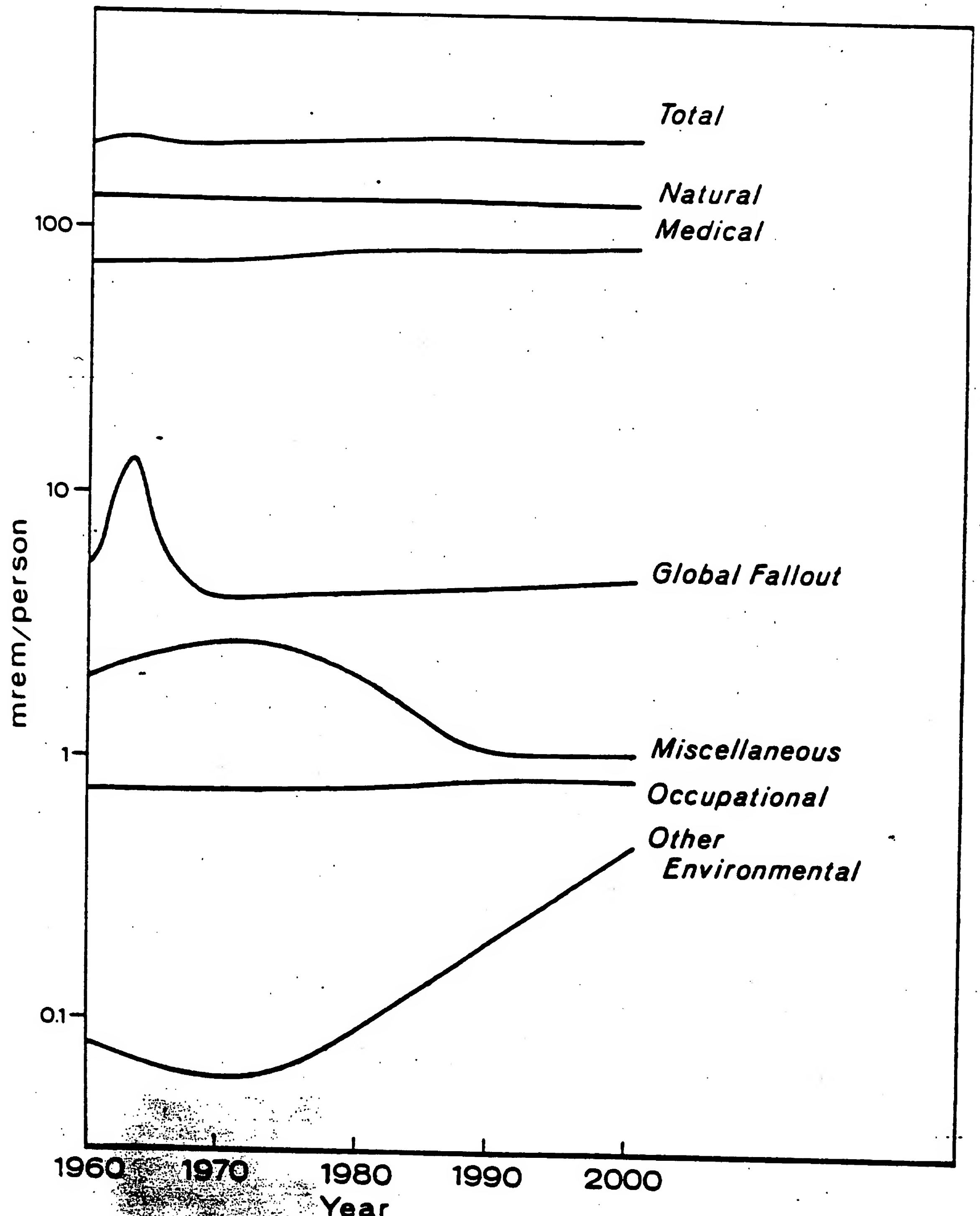
RADIONUCLIDE	AVERAGE ANNUAL WHOLE BODY DOSE (mrem)
^{3}H	0.004
^{14}C	1.0
^{40}K	17.0
^{87}Rb	0.6
^{210}Po	3.0
^{222}Rn	3.0
^{226}Ra	
^{228}Ra	

RADIATION PHYSICS

MAN MADE RADIATIONS

FALLOUT	5 mrem/yr avg.
Reactors ~~RENETORS~~ AND FUEL PROCESSING	.1 mrem/yr
MEDICAL	18 TO 136 mrem/yr GSD
MISC. (TELEVISION, COMMON PRODUCTS, AIR TRAVEL)	1.1 mrem/yr

GSD - Genetically significant Dose



SUMMARY OF ESTIMATED AVERAGE WHOLE-BODY RADIATION DOSES IN THE UNITED STATES (mrem/person)

RADIATION PHYSICS

ATOMIC STRUCTURE

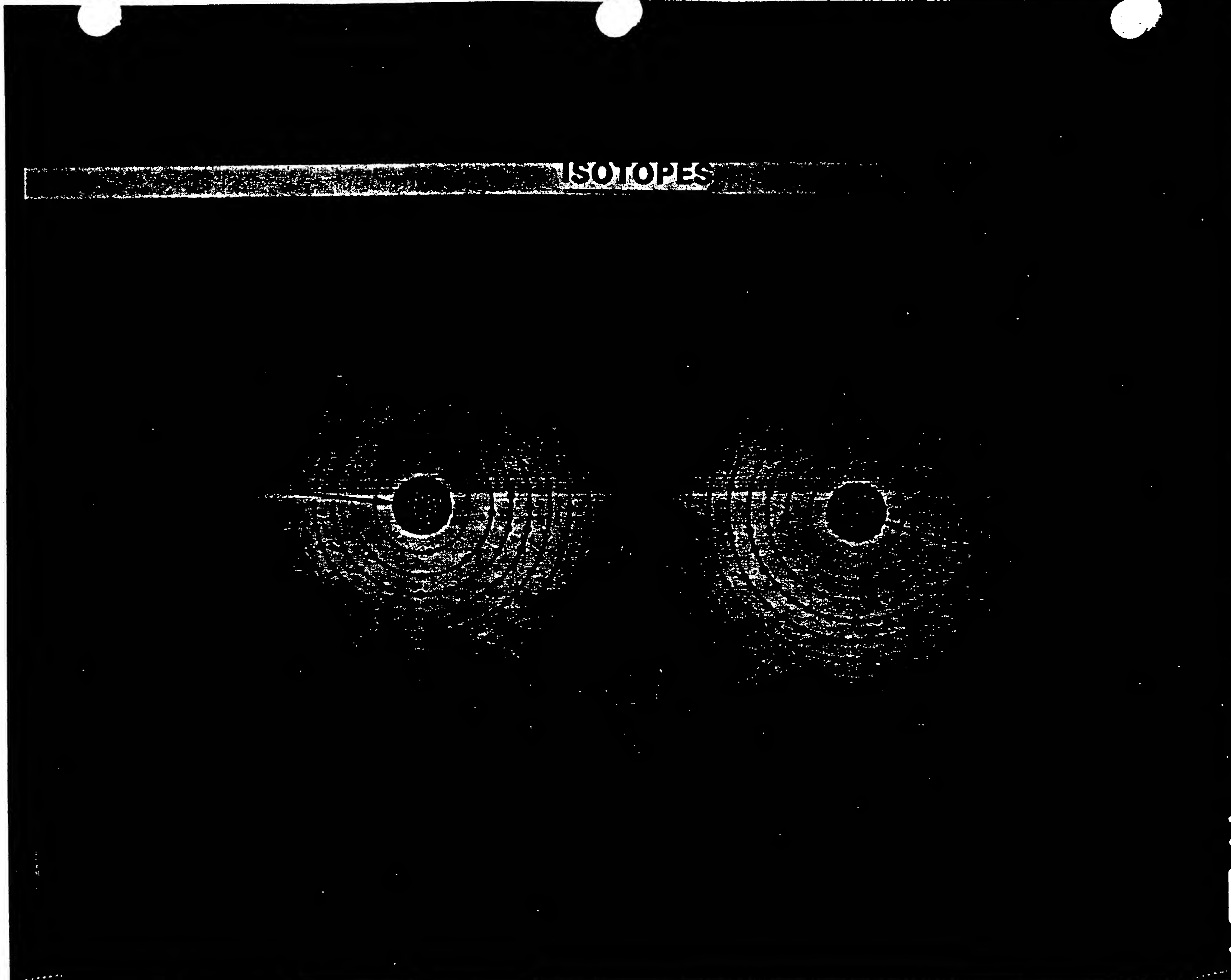
PROTON

$^{A}_{Z}X$

NEUTRON

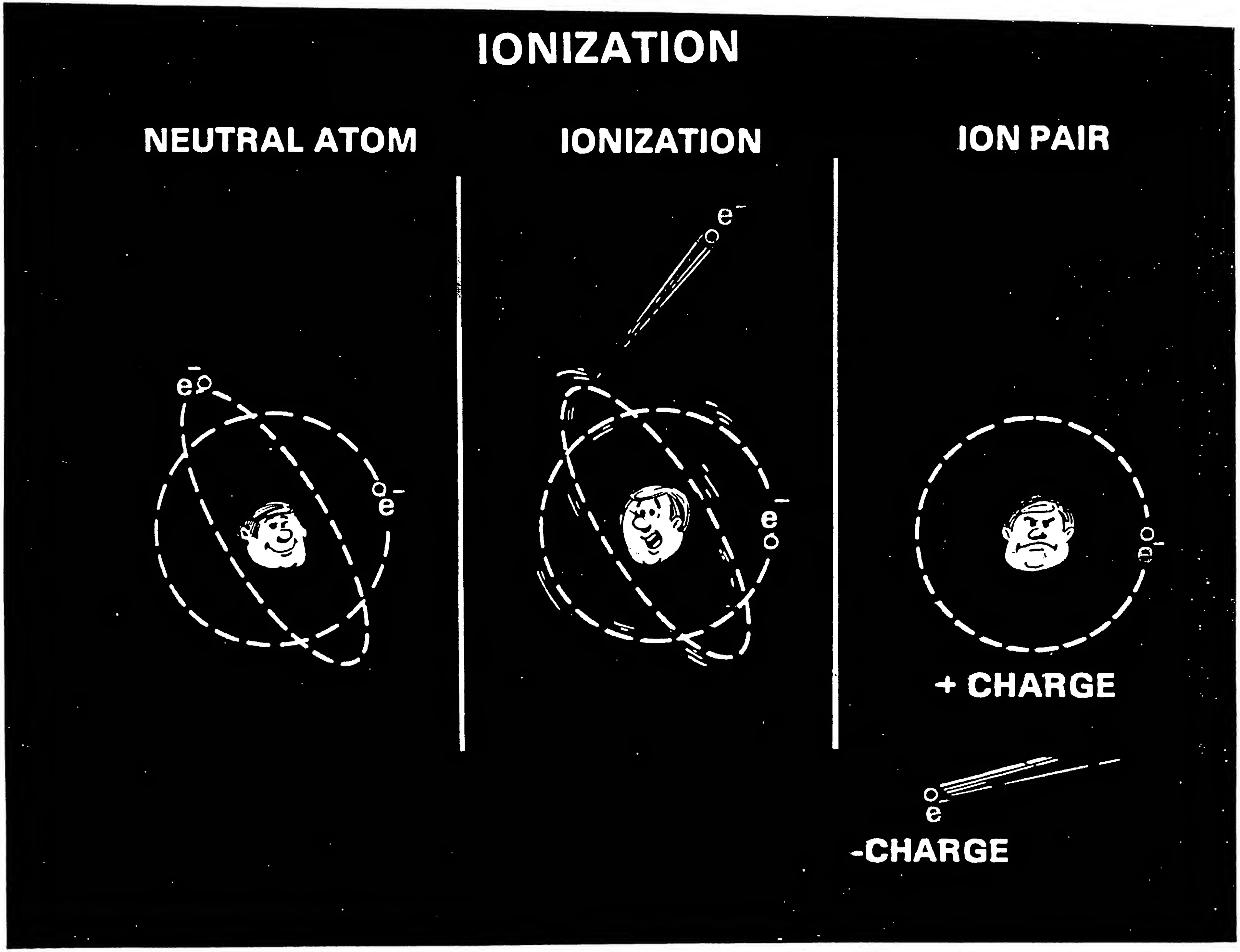
ELECTRON

A= Atomic #
Z= proton (+)


ISOTOPES

RADIATION PHYSICS

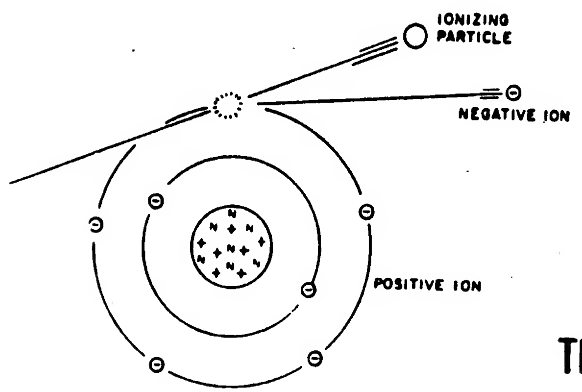
	$^{238}_{92}U$	$^{235}_{92}U$	$^{234}_{92}U$
PROTON	92	92	92
NEUTRON	146	$\cancel{146}$ 143	$\cancel{146}$ 142
ELECTRON	92	92	92


IONIZATION
NEUTRAL ATOM
IONIZATION
ION PAIR
e⁻
+ CHARGE
-CHARGE

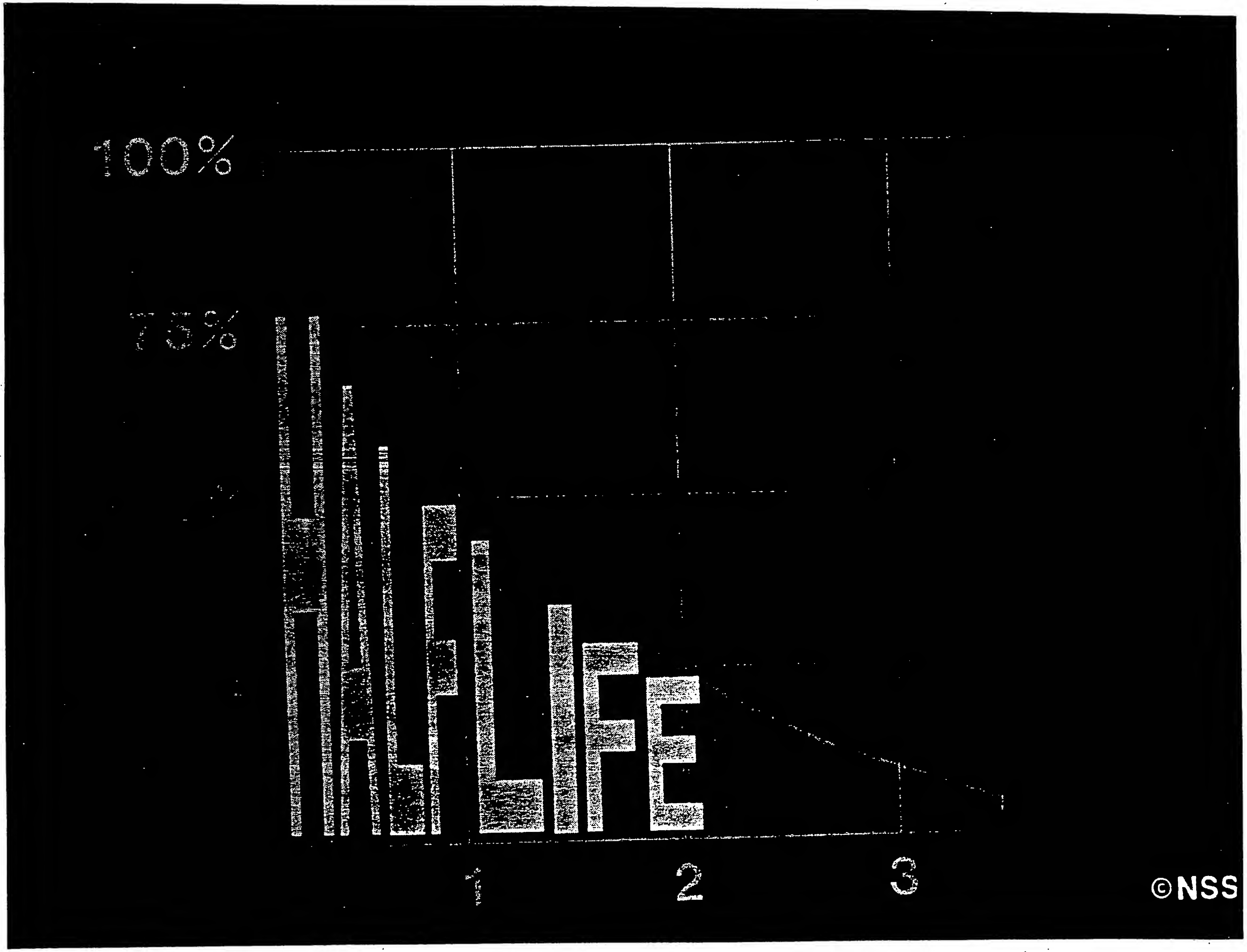
ISOTOPES OF URANIUM

RADIATION PHYSICS

IONIZATION



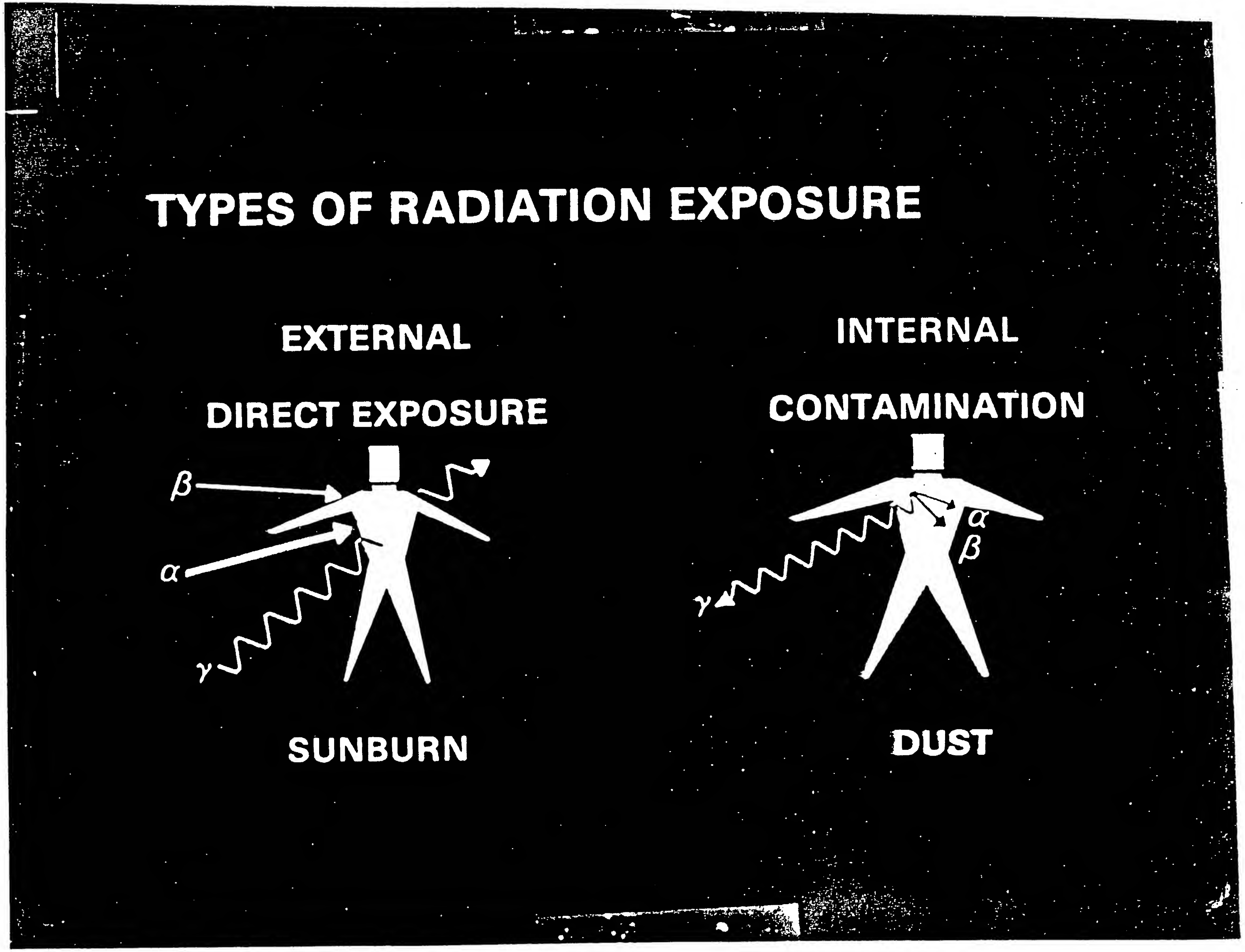
THE IONIZATION OF AN ATOM

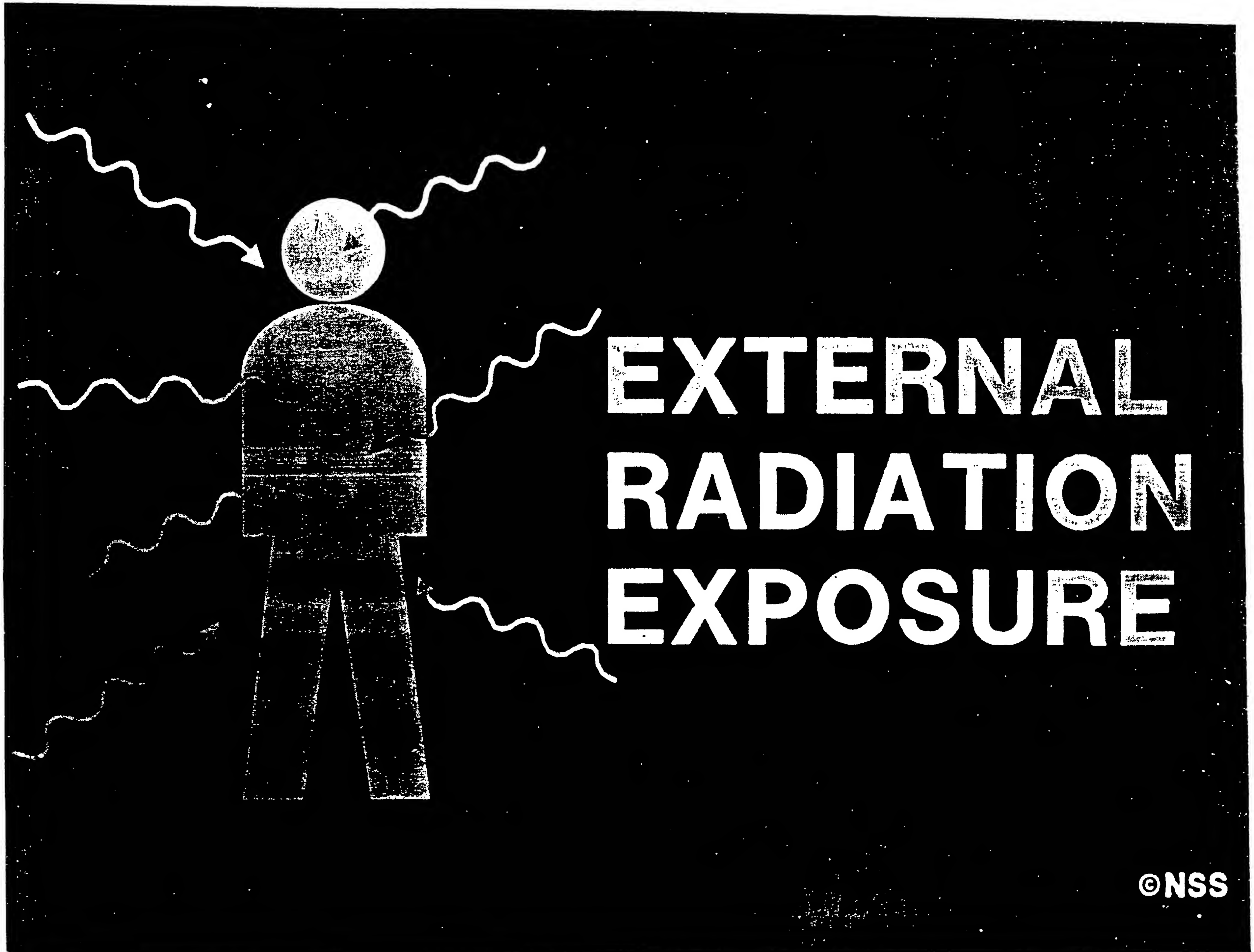

100%
75%
HALF LIFE
1
2
3
©NSS

NUCLEAR RADIATION

RADIATION TYPE	MASS	CHARGE	SPEED IN mph	RANGE IN AIR (FEET)	SHIELD
ALPHA α	4	+2	7M	$\frac{1}{4}$	PAPER
BETA β	$\frac{1}{2000}$	±1	500M	60	ALUMINUM FOIL/LUCITE
GAMMA γ	0	0	670M	5000	SEVERAL FEET CONCRETE /LEAD SHEETS
NEUTRON η	1	0	70M	3000	SEVERAL FEET WATER OR PARAFIN /GRAPHITE

RADIATION UNITS

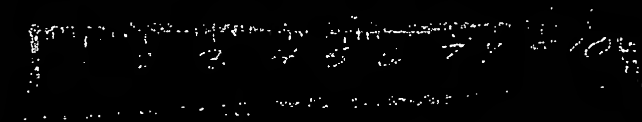

TYPES OF RADIATION EXPOSURE
EXTERNAL
DIRECT EXPOSURE
β
α
γ
SUNBURN
INTERNAL
CONTAMINATION
α
β
γ
DUST


EXTERNAL
RADIATION
EXPOSURE
©NSS

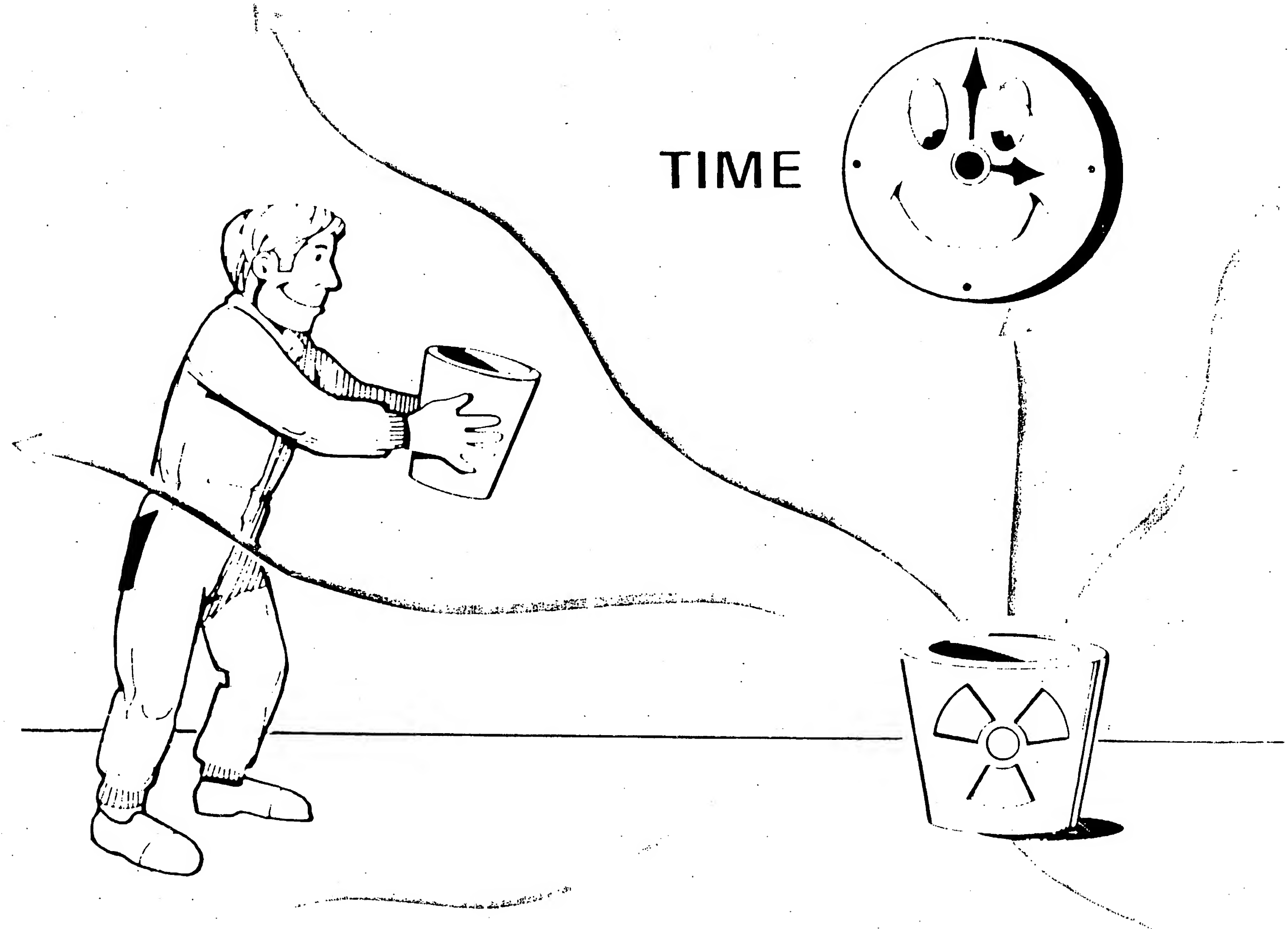
LIMITING EXTERNAL DOSE

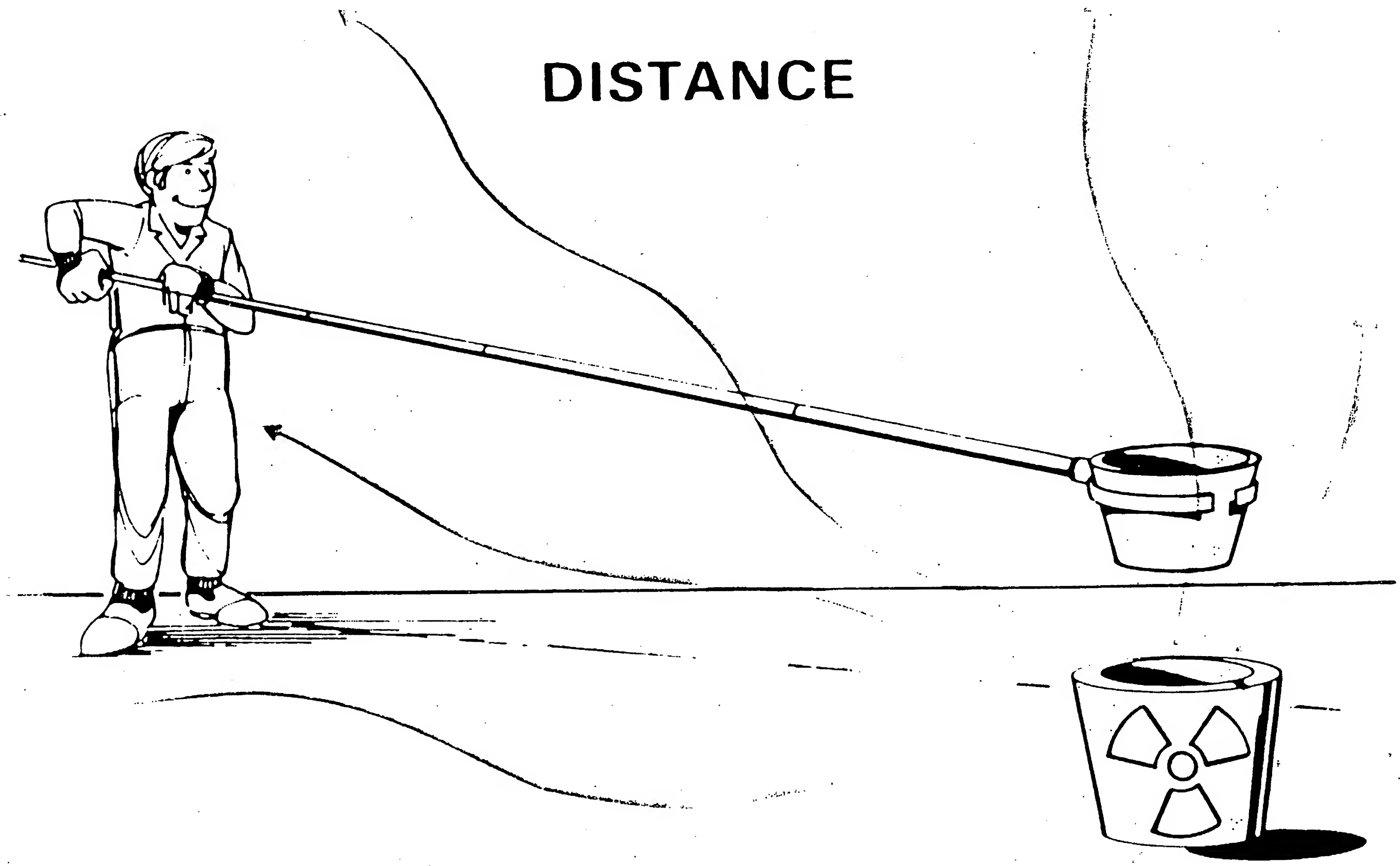
- LIMIT TIME

- MAXIMIZE DISTANCE

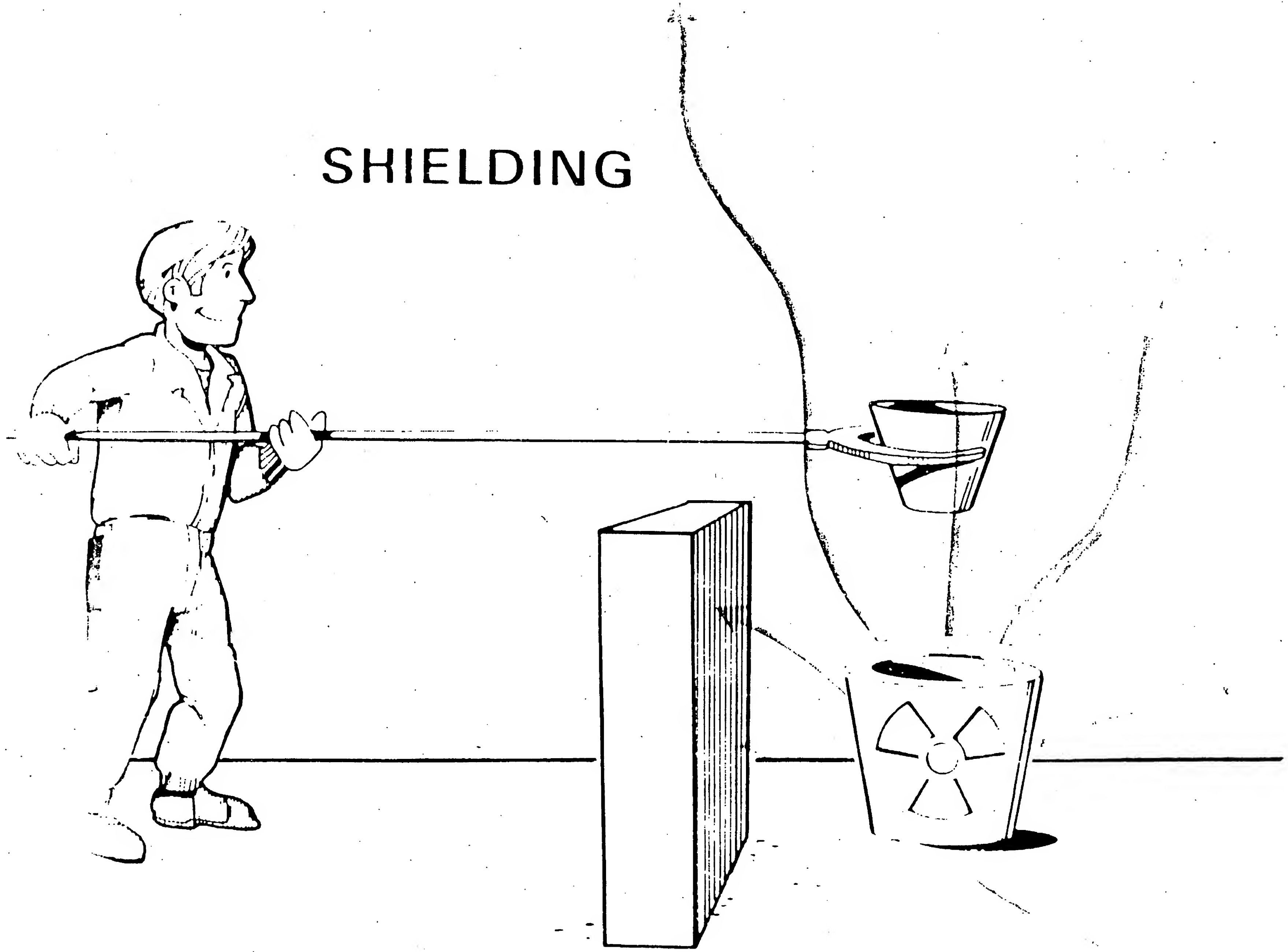


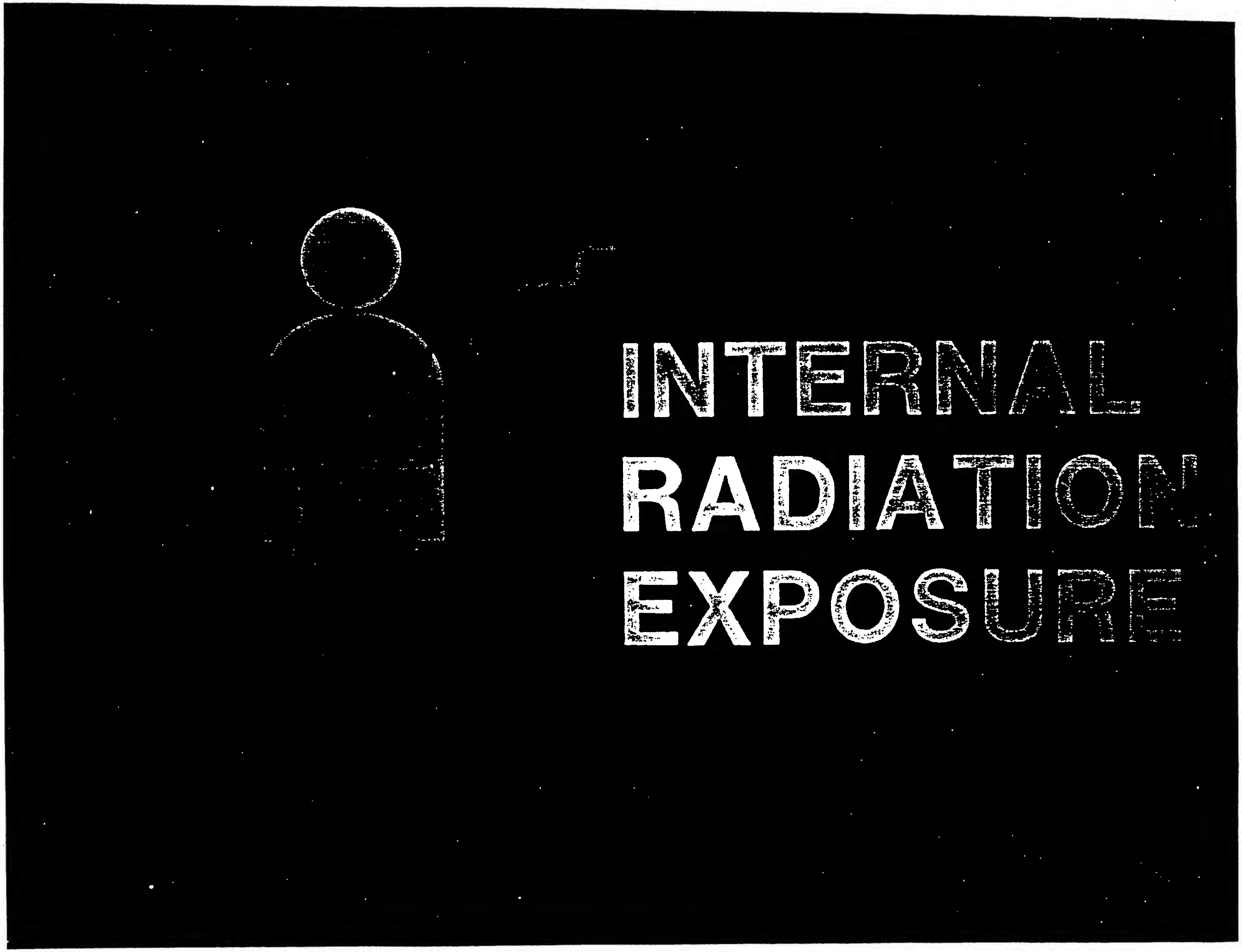
- USE SHIELDING


TIME


DISTANCE

SHIELDING

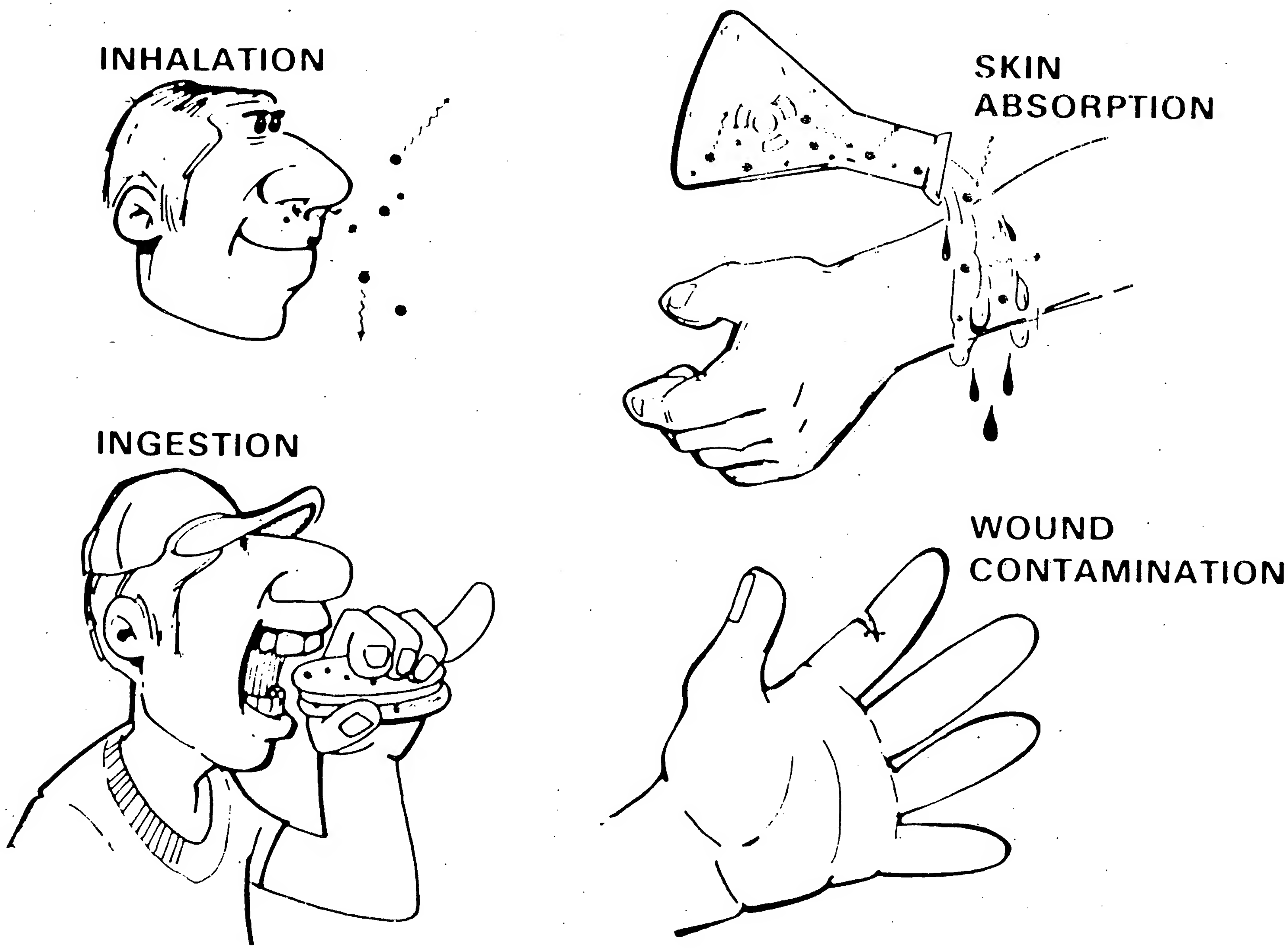


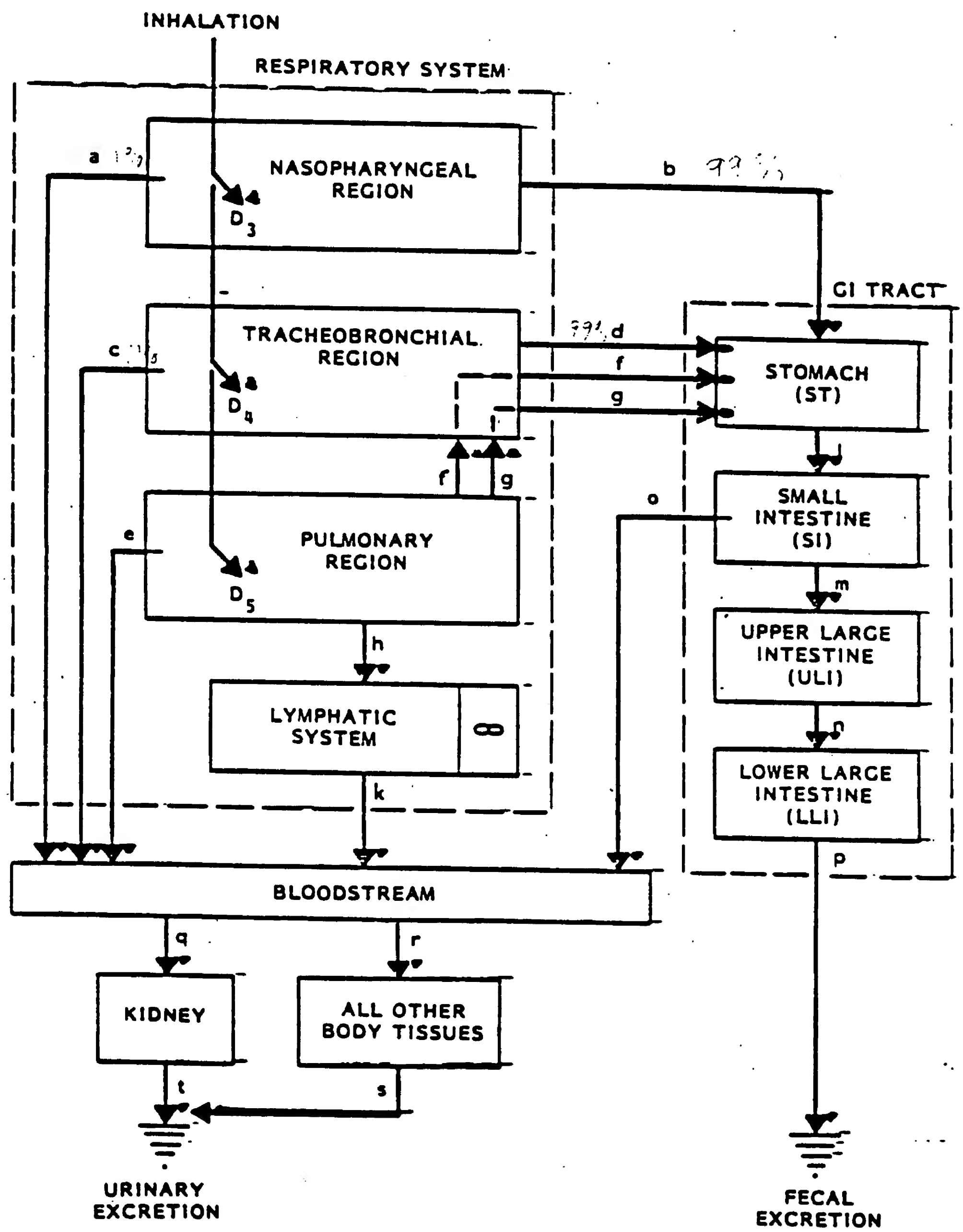

INTERNAL
RADIATION
EXPOSURE

LIMITING INTERNAL EXPOSURE

• LIMIT	CONTAMINATION AIR, FOOD, WATER
• USE	PROTECTIVE CLOTHING RESPIRATORY PROTECTION GLOVE BOXES HOODS SPECIAL PROCEDURES

ENTRY MECHANISMS





INHALATION
RESPIRATORY SYSTEM
NASOPHARYNGEAL REGION
D_3
TRACHEOBRONCHIAL REGION
D_4
PULMONARY REGION
D_5
LYMPHATIC SYSTEM
∞
a
b
c
d
e
f
g
h
i
j
k
m
n
o
p
q
r
s
t
GI TRACT
STOMACH (ST)
SMALL INTESTINE (SI)
UPPER LARGE INTESTINE (ULI)
LOWER LARGE INTESTINE (LLI)
BLOODSTREAM
KIDNEY
ALL OTHER BODY TISSUES
URINARY EXCRETION
FECAL EXCRETION

Compartment	Pathway	Uranium T	Uranium f	Thorium T	Thorium f
Nasopharyngeal	a	0.01	0.01	0.01	0.01
	b	0.4	0.99	0.4	0.99
Tracheobronchial	c	0.01	0.01	0.01	0.01
	d	0.2	0.99	0.2	0.99
Pulmonary	e	500	0.05	1460	0.05
	f	1.0	0.4	1.0	0.4
	g	500	0.4	500	0.4
	h	500	0.15	500	0.15
Lymphatic	k	1000	0.9	∞	1.0
Stomach	l	0.029	1.0	0.029	1.0
Small intestine	m	0.115	0.998	0.115	0.9998
	o	57.6	0.002	577	0.0002
Upper large intestine	n	0.385	1.0	0.385	1.0
Lower large intestine	p	0.693	1.0	0.693	1.0
Bloodstream	q	0.5	0.657	0.5	0.1
	r	0.5	0.343	0.5	0.9
All other body tissues	s	6	0.349	700	0.222
		20	0.582	8000	0.778
		1500	0.0015		
		5000	0.067		
Kidney	t	0.5	0.816	0.5	1.0
		6	0.183		
		1500	0.0008		

For Class Y Material

<u>Class D</u> - Soluble (transported) compounds - solubility half-life (time for half of the compound to be dissolved in lung fluids) of 1 to 10 days.

Ammonium diuranate (ADU)	$(NH_4)_2U_2O_7$
Uranium hexafluoride	UF_6
Uranium trioxide	UO_3
Uranyl acetate	$UO_2(C_2H_3O_2)_2$
Uranyl chloride	UO_2Cl_2
Uranyl fluoride	UO_2F_2
Uranyl nitrate	$UO_2(NO_3)_2$
Uranyl sulfate	UO_2SO_4

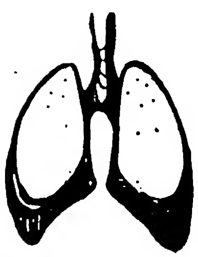
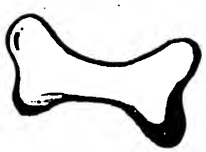
<u>Class W</u> - moderately soluble (slowly-transportable) compounds - estimated solubility half-life of 10 to 100 days inclusive.

Uranium dioxide	UO_2
Uranium tetroxide	UO_4

<u>Class Y</u> - relatively insoluble (very slowly-transportable) compounds - estimated solubility half-life of greater than 100 days.

Uranium aluminide	UAl_x
Uranium carbide	UC_2
Uranium dioxide (high-fired)	UO_2
Uranium oxide	U_3O_8
Uranium tetrafluoride	UF_4
Uranium-zirconium alloy	UZr

CRITICAL ORGANS

ORGAN		ISOTOPE
 KIDNEY	—	URANIUM (CHEMICAL CONCERN) 10 CFR 2
 LUNG	—	URANIUM AND THORIUM
 BONE	—	ENRICHED URANIUM AND THORIUM

BIOLOGICAL HALF-LIFE

THE AMOUNT OF TIME IT TAKES FOR HALF OF A SUBSTANCE TO LEAVE THE BODY DUE TO NATURAL PROCESSES SUCH AS DIGESTION. DEPENDS ON CHEMICAL PROPERTIES OF THE SUBSTANCE, NOT NUCLEAR PROPERTIES.

RADIOLOGICAL HALF-LIFE

THE AMOUNT OF TIME IT TAKES FOR HALF OF A RADIONUCLIDE TO UNDERGO RADIOACTIVE DECAY. INDEPENDENT OF CHEMICAL PROPERTIES.

EFFECTIVE HALF LIFE

$$T_{1/2}\ (\text{Eff.}) = \frac{T_{1/2}\ (\text{Biol.}) \times T_{1/2}\ (\text{Rad.})}{T_{1/2}\ (\text{Biol.}) + T_{1/2}\ (\text{Rad.})}$$

INTERNAL DOSES

MPBB MAXIMUM PERMISSIBLE BODY BURDEN

MPC MAXIMUM PERMISSIBLE CONCENTRATION

@ [illegible] HR/WEEK x [illegible] WK/YR = MP

[illegible] GIVES [illegible]UM [illegible]SE TO CRITICAL ORGAN

to 1.25 rem/qtr.

10 CFR

MPC

OCCUPATIONAL

	SOLUBLE	INSOLUBLE
U^{238}	7×10^{-11} µCI/ML	1×10^{-10} µCI/ML
U NAT.	1×10^{-10} µCI/ML	1×10^{-10} µCI/ML
U DEP.	7.4×10^{-11} µCI/ML	1×10^{-10} µCI/ML

MPC

OCCUPATIONAL

(10CFR20)

0.2 MILLIGRAMS U / $METER^3$

CONCENTRATION X TIME OF EXPOSURE/WK $\leq 8 \times 10^{-3}$ SA μCI-HR/ML

$\boxed{SA_{DEP} = 3.6 \times 10^{-7} \text{ CI/GU}}$

TLV

NIOSH / OSHA

	Permissible Exposure Level	IDLH
Uranium soluble	0.05 mg/m^3	20 mg/m^3
Uranium insoluble	0.25 mg/m^3	30 mg/m^3
(ACGIH)	0.2 mg/m^3	
MPBB (kidney)	5. x 10^{-3} µCi	

Maximum Kidney Burden (chemical toxicity) 3 µg/gr of kidney

BIOASSAY

URINALYSIS

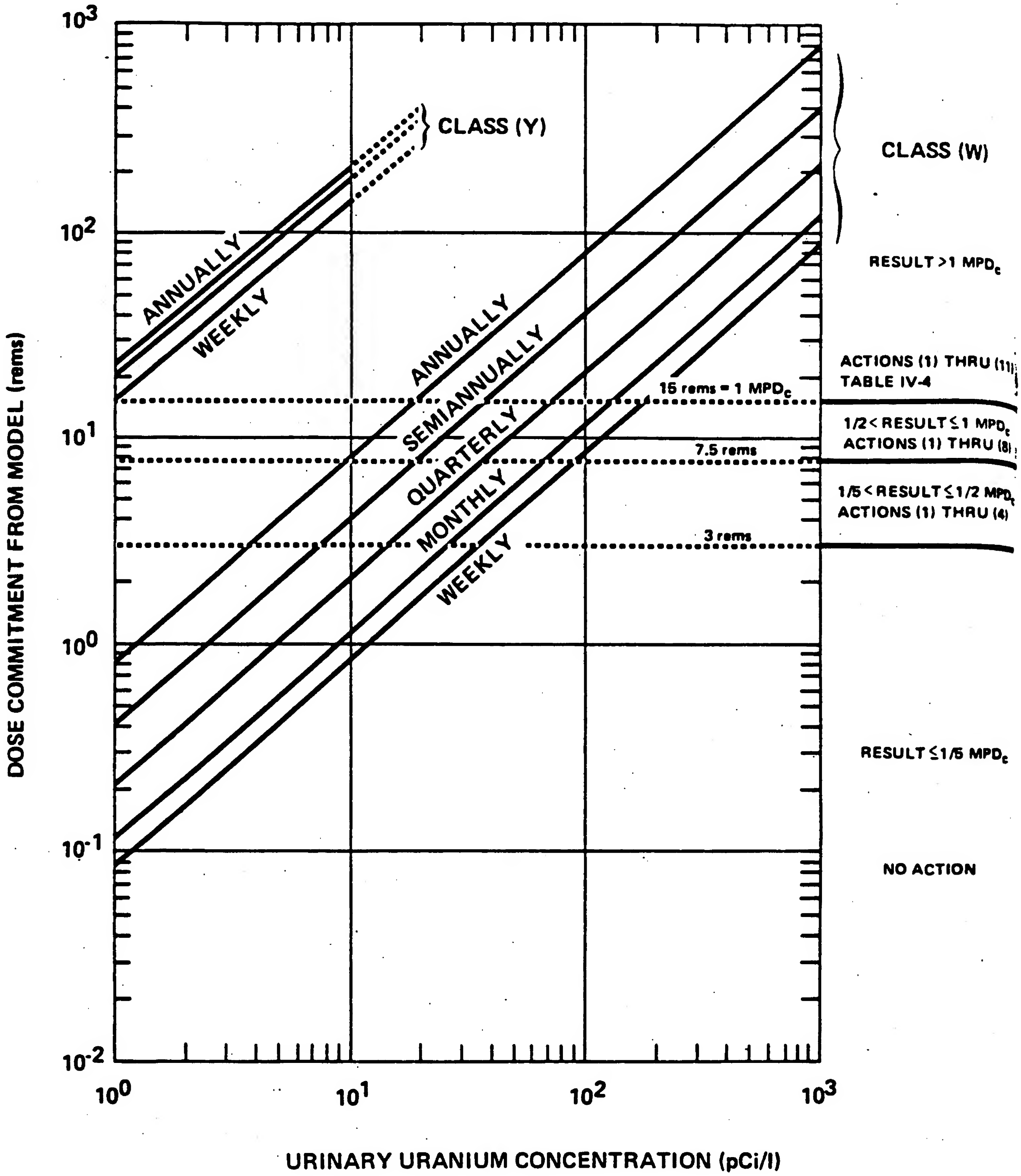
FECAL ANALYSIS

WHOLE BODY COUNTING

LUNG COUNTING

BIOASSAY

SOLUBLE URANIUM	URINALYSIS
INSOLUBLE URANIUM	LUNG COUNTING
	WHOLE BODY COUNTING
	FECAL ANALYSIS



Dose Commitment Indicated by Model vs. Urinary Uranium Concentration, Class (W) and (Y), Single Intake

From Wash. 1251

BIOLOGICAL EFFECTS

PART OF BODY EXPOSED

AMOUNT OF DOSE RECEIVED

PERIOD OF TIME

TYPE OF RADIATION

SHORT TERM EFFECTS

- NAUSEA
- VOMITING
- WEAKNESS
- DIARRHEA

LONG TERM EFFECTS

- CATARACTS
- LEUKEMIA
- INCREASED DEGENERATIVE DISEASES
- GENETIC MUTATIONS

SUMMARY OF EFFECTS ON MAN AS A RESULT OF SHORT-TERM WHOLE-BODY EXTERNAL EXPOSURE TO RADIATION

DOSE EQUIVALENT	EFFECTS ON MAN
0 TO 25 rems	NO DETECTABLE CLINICAL EFFECTS DELAYED EFFECTS MAY OCCUR
25 TO 100 rems	SLIGHT TRANSIENT REDUCTIONS IN LYMPHOCYTES AND NEUTROPHILS DISABLING SICKNESS NOT COMMON; EXPOSED INDIVIDUALS SHOULD BE ABLE TO PROCEED WITH USUAL TASKS DELAYED EFFECTS POSSIBLE, BUT SERIOUS EFFECTS ON AVERAGE INDIVIDUAL VERY IMPROBABLE
100 TO 200 rems	NAUSEA AND FATIGUE, WITH POSSIBLE VOMITING ABOVE 125 rems IN ABOUT 20 TO 25 PERCENT OF PEOPLE REDUCTION IN LYMPHOCYTES AND NEUTROPHILS, WITH DELAYED RECOVERY DELAYED EFFECTS MAY SHORTEN LIFE EXPECTANCY IN THE ORDER OF 1 PERCENT
200 TO 300 rems	NAUSEA AND VOMITING ON FIRST DAY LATENT PERIOD UP TO 2 WEEKS, OR PERHAPS LONGER FOLLOWING LATENT PERIOD, SYMPTOMS APPEAR, BUT ARE NOT SEVERE: LOSS OF APPETITE, AND GENERAL MALAISE, SORE THROAT, PALLOR, PETECHIAE, DIARRHEA, MODERATE EMACIATION RECOVERY LIKELY IN ABOUT 3 MONTHS, UNLESS COMPLICATED BY PREVIOUS POOR HEALTH OR BY SUPERIMPOSED INJURIES OR INFECTIONS
300 TO 600 rems	NAUSEA, VOMITING, AND DIARRHEA IN FIRST FEW HOURS LATENT PERIOD, WITH NO DEFINITE SYMPTOMS, PERHAPS AS LONG AS 1 WEEK EPILATION, LOSS OF APPETITE, GENERAL MALAISE, AND FEVER DURING SECOND WEEK, FOLLOWED BY HEMORRHAGE, PURPURA, PETECHIAE, INFLAMMATION OF MOUTH AND THROAT, DIARRHEA, AND EMACIATION IN THE THIRD WEEK SOME DEATHS IN 2 TO 6 WEEKS; POSSIBLE EVENTUAL DEATH TO 50 PERCENT OF THE EXPOSED INDIVIDUALS [illegible] ABOUT 450 rems. CONVALESCENCE OF OTHERS ABOUT [illegible]
600 rems OR MORE	NAUSEA, VOMITING, AND DIARRHEA IN FIRST FEW HOURS SHORT LATENT PERIOD, WITH NO DEFINITE SYMPTOMS, IN SOME CASES, DURING FIRST WEEK DIARRHEA, HEMORRHAGE, [illegible] OF MOUTH AND THROAT, AND FEVER [illegible] WEEK RAPID EMACIATION AND [illegible] SECOND WEEK, WITH POSSIBLE EVENTUAL [illegible] PERCENT OF EXPOSED INDIVIDUALS

From: Saenger, E.L., ed., Med[illegible]
United States Atomic Energy [illegible]

PERIOD OF EXPOSURE

ACUTE EXPOSURE — SUDDEN, WITHIN 1 HOUR

CHRONIC EXPOSURE — EXTENDED: RECEIVED OVER A NUMBER OF MONTHS OR YEARS

PURPOSE OF A RADIATION SAFETY PROGRAM INVOLVING DU

A. ALARA/MINIMIZING EXPOSURE
   1. EXTERNAL EXPOSURE CONTROL
   2. INTERNAL EXPOSURE CONTROL

B. CONTAMINATION CONTROL

C. TO PREDICT AND CONTROL RADIOLOGICAL HAZARDS

EXTERNAL EXPOSURE FROM DU

A. Hazards
   1. Gamma Radiation (Penetrating)
   2. Beta Radiation (Non-Penetrating)

B. Dose Reduction Methods
   1. Time
   2. Distance
   3. Shielding

INTERNAL EXPOSURE FROM DU

A. HAZARDS
   1. ALPHA
   2. BETA
   3. GAMMA

B. DOSE REDUCTION METHODS
   1. CONTAMINATION CONTROL
   2. FILTRATION SYSTEMS
   3. RESPIRATORY PROTECTION

DU CONTAMINATION CONTROL

A. Operation Specific
   1. Routine Surveys
   2. Follow-Up
      - Posting
      - Decontamination

PREDICTING AND CONTROLLING RADIOLOGICAL HAZARDS

A. Historical Data

B. Current Conditions

C. Operational Knowledge

D. Procedure Compliance

E. Sound Radiation Safety Practices

RADIOLOGICAL SURVEILLANCE PROGRAM

- Administration
- Measurements
- Protective Measures

PROGRAM ADMINISTRATION

- Provide and Ensure Compliance With Procedures
- Ensure Regulatory Compliance
- Management Committment
- Documentation of Data

RADIOLOGICAL MEASUREMENTS

- DOSE-LEVEL MEASUREMENTS
  - AREA MONITORING
  - PERSONNEL MONITORING
  - RADIOACTIVE SHIPMENT SURVEYS
- SURFACE CONTAMINATION MEASUREMENTS
  - ROUTINE AREA SURVEYS
  - TOOL/EQUIPMENT SURVEYS
  - PERSONNEL RELEASE SURVEYS
  - DECONTAMINATION OPERATIONS
- AIRBORNE CONTAMINATION MEASUREMENTS
  - AIR SAMPLING
  - SMEARS/SWIPES
- DOSIMETRY
- BIO-ASSAY

PROTECTIVE MEASURES

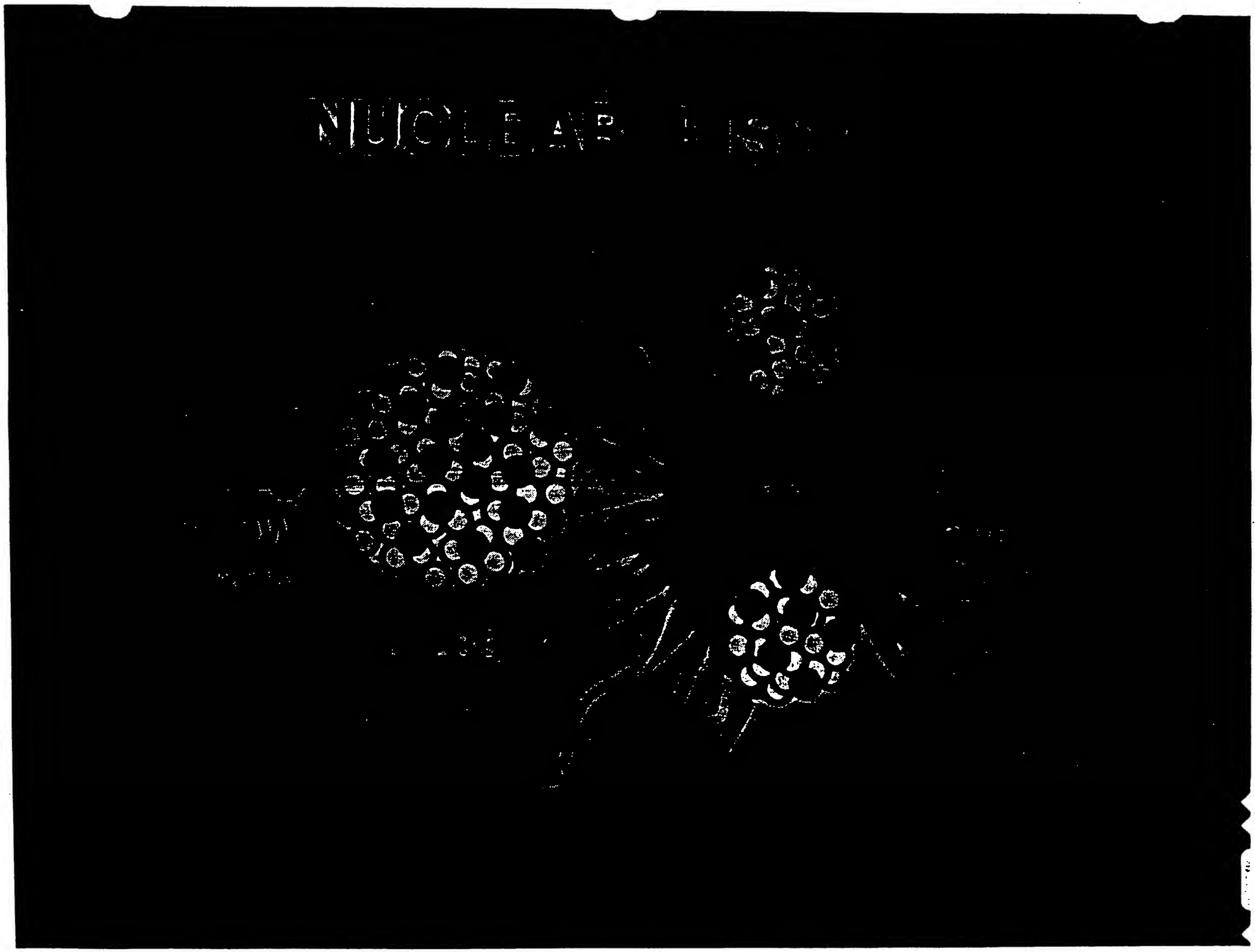
- Protective Clothing
- Respiratory Protection
- Shielding
- Engineering Controls

HISTORY OF DU PRODUCTION

MANHATTAN PROJECT

NUCLEAR WEAPON DEVELOPMENT

$^{235}_{92}U$ $^{239}_{94}PU$


NUCLEAR

MILITARY USES OF DU

- Aircraft and Missile Conterweights/Ballast
- Balancing Control Surfaces and Vibration Damping on Aircraft
- Spotter Rounds
- Armor Piercing Projectiles
- Speçial Purpose Artillery Shells
- Weapons

ADVANTAGES OF DU

- HIGH DENSITY
- HIGH STRENGTH
- PYROPHORICITY
- EASE OF FABRICATION
- RELATIVELY LOW FABRICATION COSTS
- AVAILABILITY

Tungsten- main competition

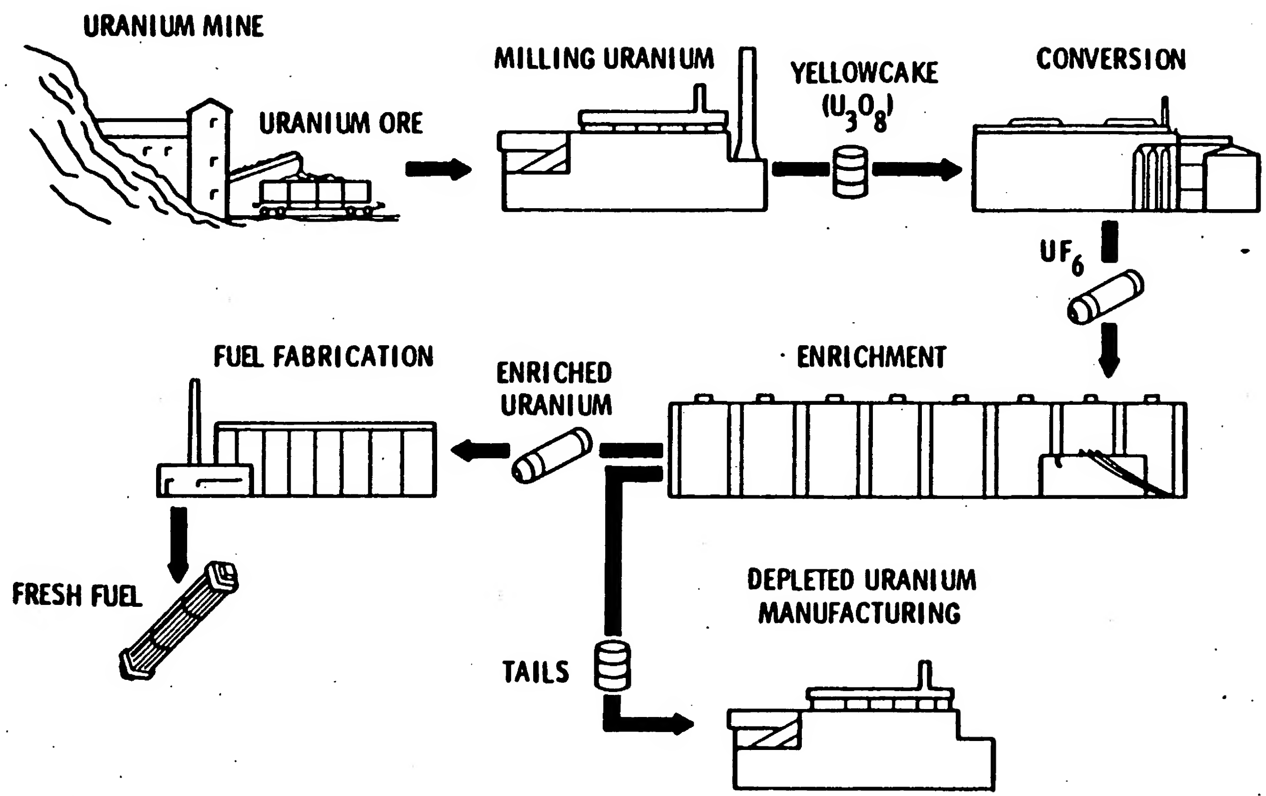
DISADVANTAGES OF DU

- Radioactive Material
- Pyrophoricity of Chips and Grindings
- Increasing Disposal Costs

URANIUM MINING

RADIATION EXPOSURES

EXTERNAL	DEPENDENT ON ORE GRADE
	<1 MEN/HR TYPICAL
INTERNAL	RADON & DAUGHTER PRODUCTS



Front End of the Uranium Fuel Cycle (ERDA 1975)

WORKING LEVEL

WORKING LEVEL - A WORKING LEVEL IS EQUIVALENT TO ANY COMBINATION OF RADON DAUGHTERS IN ONE LITER OF AIR WHICH WILL RESULT IN THE EMISSION OF 1.3×10^5 MEV OF ALPHA ENERGY IN THE COMPLETE DECAY THROUGH ^{214}PO. THIS POTENTIAL ALPHA ENERGY WILL OCCUR WHEN 100 PCI/ℓ OF ^{222}RN IN AIR IS IN EQUILIBRIUM WITH ITS DAUGHTER PRODUCTS.

1 WLM	=	170 WL-HR
LIMIT		0.3 WL
		4 WLM PER YEAR

Selected Methods for Determining Radon Concentrations in Air

Method	Application	Sensitivity	Comments
Lucas cell scintillation flask	Grab or continuous	<0.1 pCi/ℓ	Inexpensive, generally reliable
Two filter, delayed counting	Grab or continuous	<0.1 pCi/ℓ	
Air collection and counting	Grab or continuous	0.05 pCi/ℓ	
Passive inverted funnel with TLD chips	Continuous	0.05 pCi/ℓ	Quiet, effective for integration, inexpensive
Activated charcoal collections	Continuous	0.01 pCi/ℓ	
Track etch dosimeters	Continuous	100 pCi/ℓ	Inexpensive, track counting required

Selected Methods for Determining Radon Daughter Concentrations in Air

Method	Application	Sensitivity	Comments
✓ Kusnetz and Tsivoglou filters	Grab sampling	0.0005 WL	Commonly used, simple, and inexpensive
Modified Kusnetz method	Grab sampling	0.0005 WL	Integration device or alpha spectrometer required
Integrating pump sampler with TLD detector	Continuous	1 WL-hr	Noise, requires 120 VAC power
Alpha track etch film	Continuous	5 WL-hr	Inexpensive, but track counting required
Instant working level meter	Grab sampling	0.01 WL	Portable, quick, expensive, easy to use

WORKING LEVEL

KUSNETZ METHOD

$$WL = \frac{CPM \times E}{Vol \times TF}$$

CPM = AVERAGE COUNT RATE OF SAMPLE IN COUNTS PER MINUTE

E = DETECTOR EFFICIENCY

VOL = TOTAL VOLUME OF AIR SAMPLED (LITERS)

TF = TIME FACTOR FROM KUSNETZ TABLE.

Time factor as a function of Delay Time for the Modified Kusnetz Method

This table gives the time factor (TF)[(a)] required in the modified Kusnetz equation as a function of delay time. The delay time is given in minutes and is equal to the difference between the counting midpoint (middle of counting start and end times from the sample analysis data sheet) and the collection end time from the sample collection data sheet.

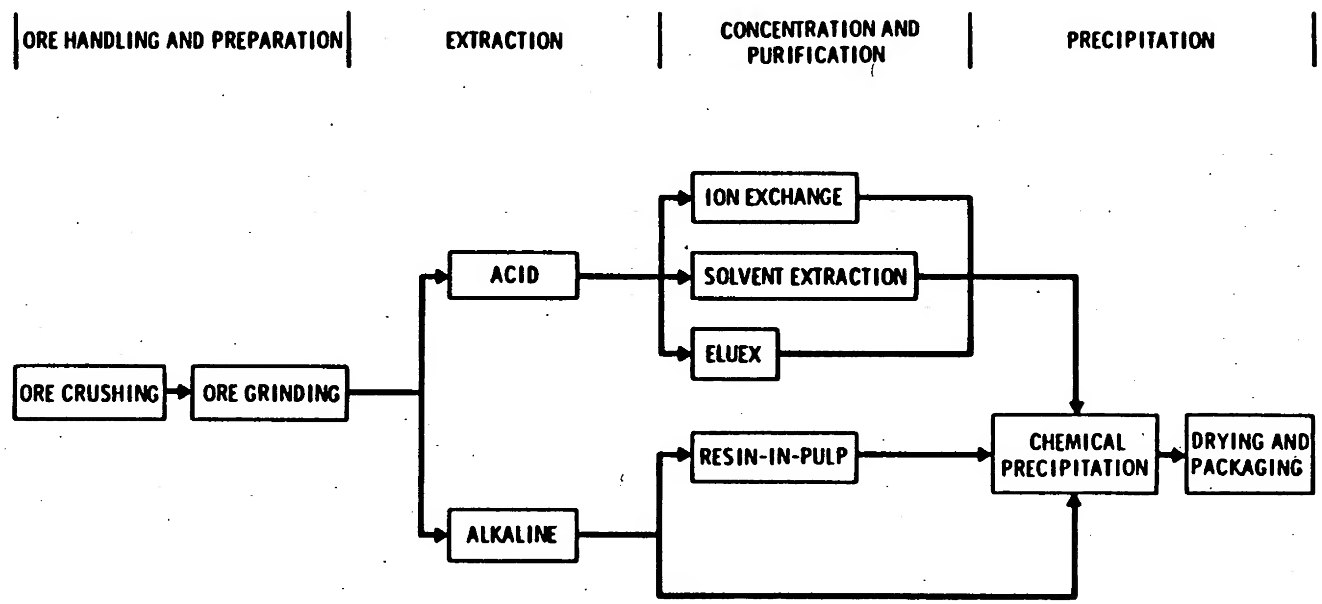
Delay time, min	↔ TF	Delay Time, min	↔ TF	Delay Time, min	↔ TF
40	150	57	116	74	84
41	148	58	114	75	83
42	146	59	112	76	82
43	144	60	110	77	81
44	142	61	108	78	78
45	140	62	106	79	76
46	138	63	104	80	75
47	136	64	102	81	74
48	134	65	100	82	73
49	132	66	98	83	71
50	130	67	96	84	69
51	128	68	94	85	68
52	126	69	92	86	66
53	124	70	90	87	65
54	122	71	89	88	63
55	120	72	87	89	61
56	118	73	85	90	60

(a) Taken from Radiation Monitoring by the U.S. Dept. of Labor, Mine Safety and Health Administration.

URANIUM MILLING

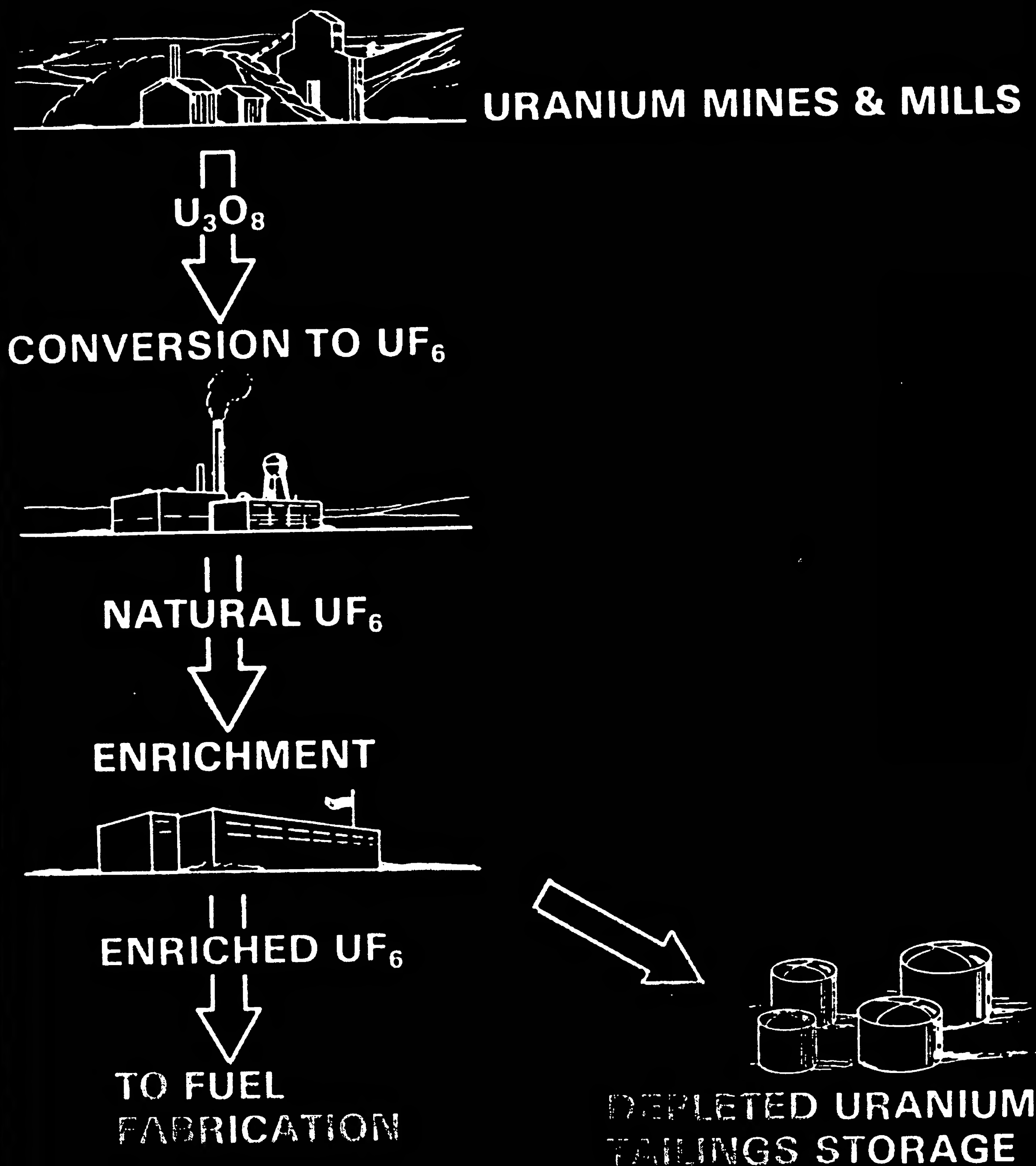
RADIATION EXPOSURES

EXTERNAL	<1 TO 5 MREM/HR
INTERNAL	OREDUST PRODUCT



Flow Diagram of Basic Conventional Milling Steps

URANIUM ENRICHMENT PROCESS



URANIUM CONVERSION TO ORANGE SALT

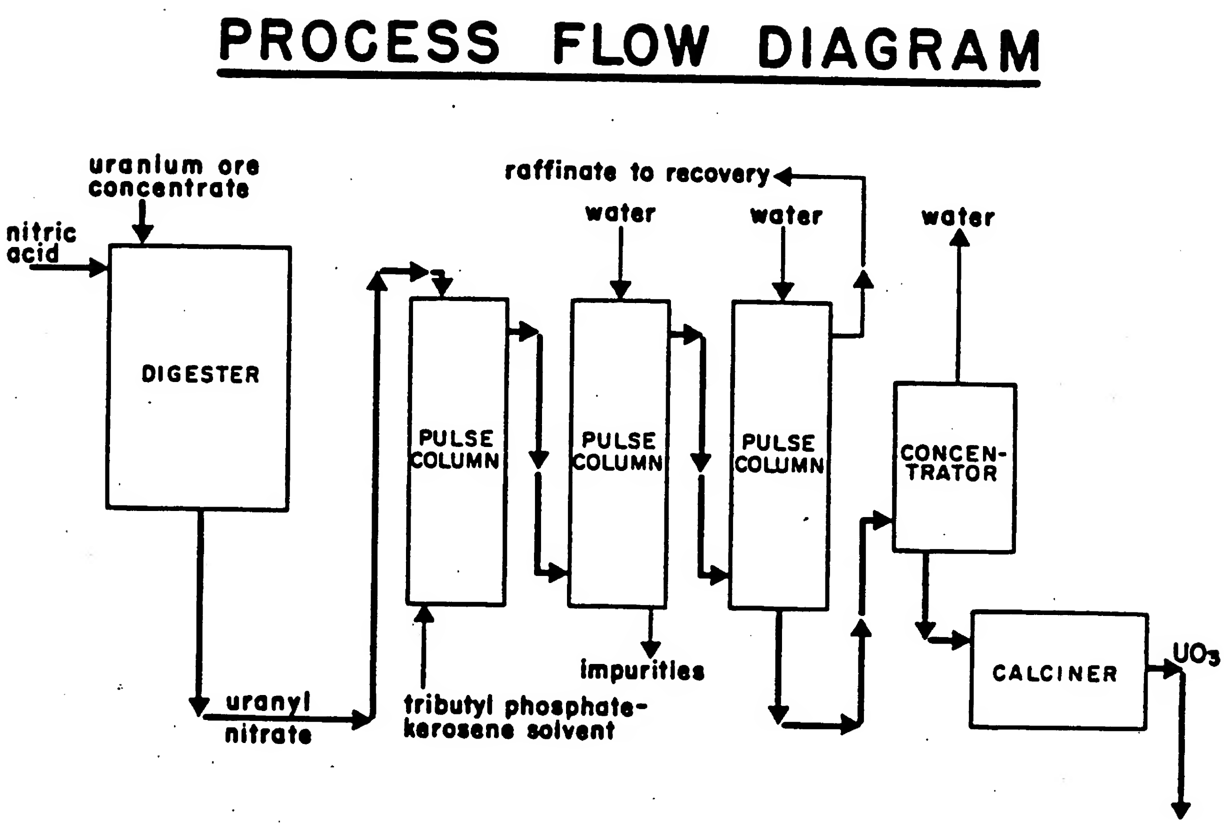
$$UO_2(NO_3)_2 \;\; xH_2O \longrightarrow UO_3 + NO + NO_2 + O_2 + xH_2O$$

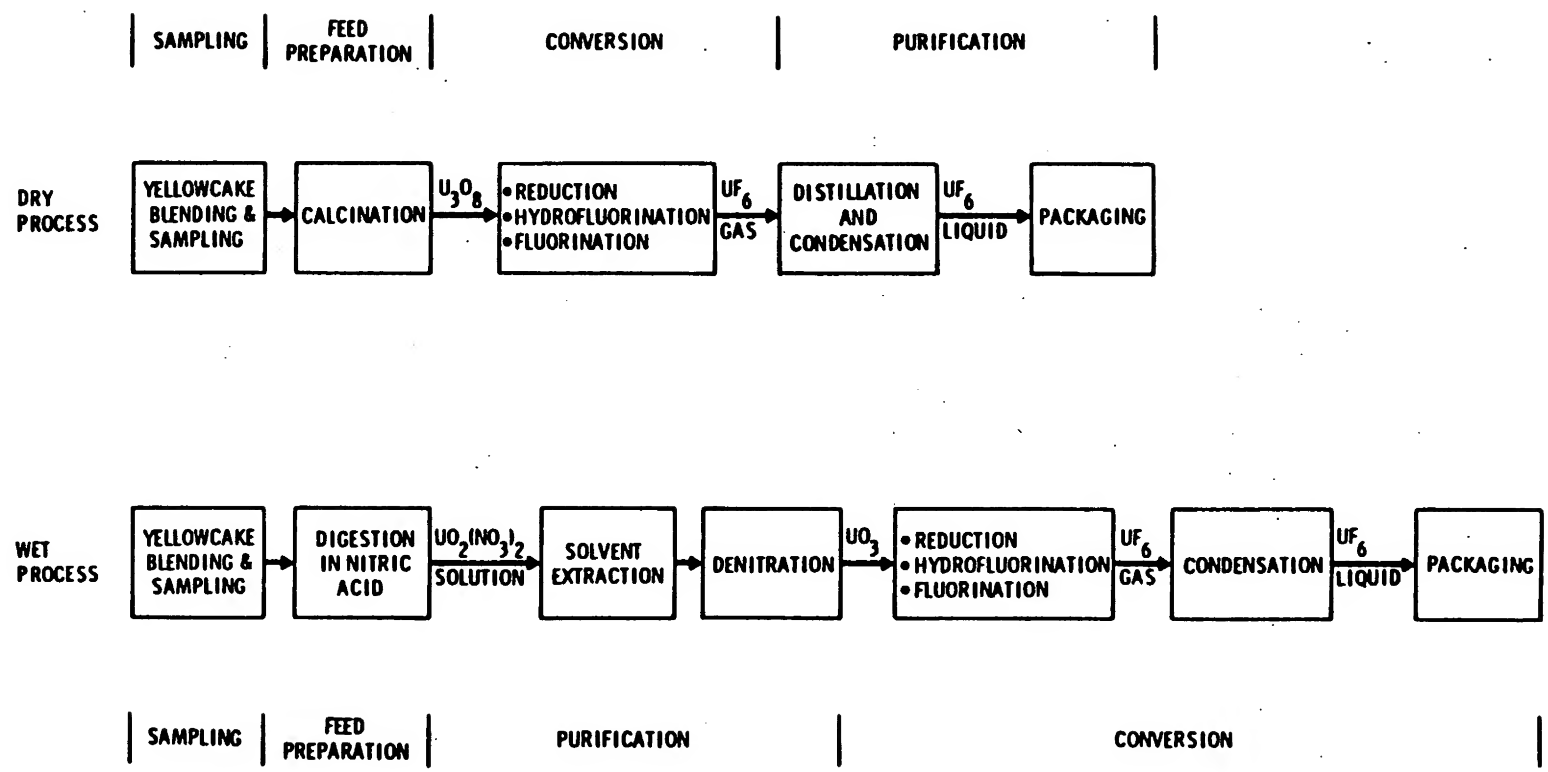
PRODUCT - SPDERIODS AVERAGING 150 μ ~~MREM~~ DIAMETER

DRY - DENSE

WASTEPRODUCTS CONCENTRATE DECAY PRODUCTS

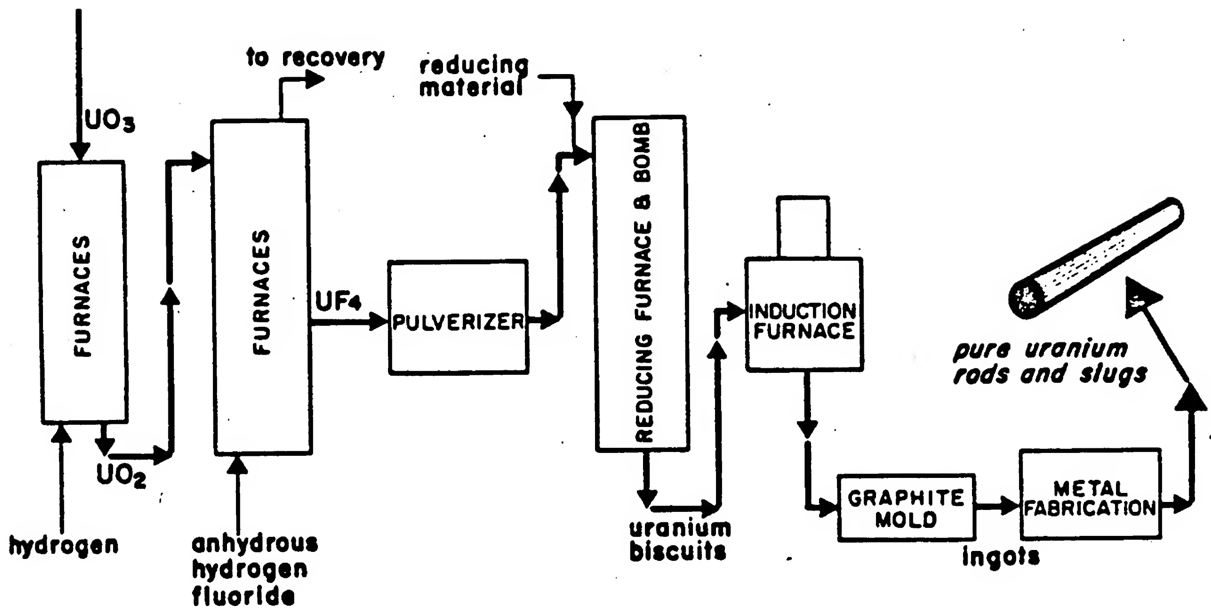
URANIUM CONVERSION TO ORANGE SALT UO_3





Flow Diagram of Conversion Processes

ORANGE SALT, GREEN SALT, METAL



- Process Flow Diagram

SOURCES OF EXPOSURE

Changing hoppers
Lidding and delidding drums
Handling contaminated drums
Adjusting weights at filling stations
Dumping drums of concentrate
Operating pot filling machine in metals plant
Breakout of furnace pots and molds
Cleaning uranium surfaces - regulus or ingot
Cleaning graphite crucibles and molds
Reassembly of crucible and mold parts
Operating crushing or grinding equipment
Changing receiving drums at dust collectors
Cleaning out dust collector housings
Cleaning out furnace enclosures
Breaking up clogged material in containers, conveyors, downcomers, and other equipment

HEALTH PHYSICS CONCERNS

UF_4 - DRY GRANULAR POWDER

SHIPPING CONTAINER - 5 GAL METAL CANS
DOSE RATES THRU METAL <5 MR/HR
UNSHIELDED MATERIAL UP TO 225 MRAD/HR

CONTAMINATION CONTROL

HEALTH PHYSICS CONCERNS

FILTERATION SYSTEMS

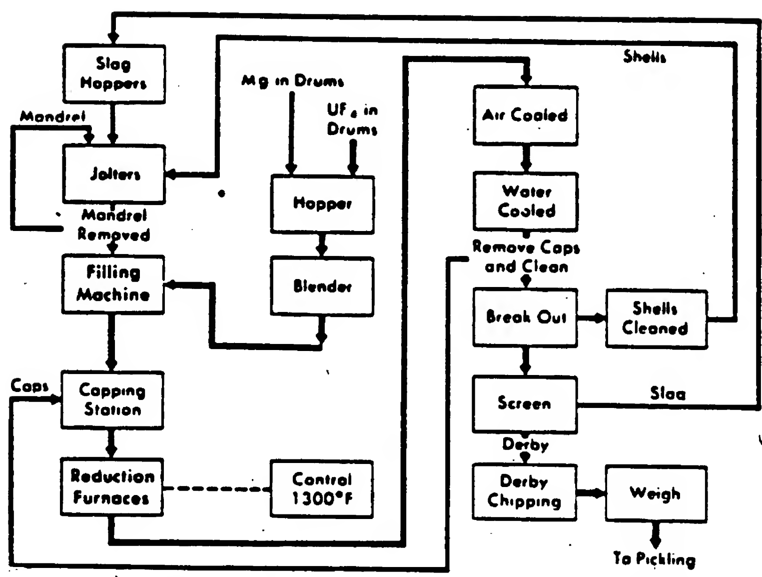
- HEPA FILTERS
- FILTER TESTING
- INTAKE - EXHAUST LOCATIONS

HEALTH PHYSICS CONCERNS

Respiratory Protection

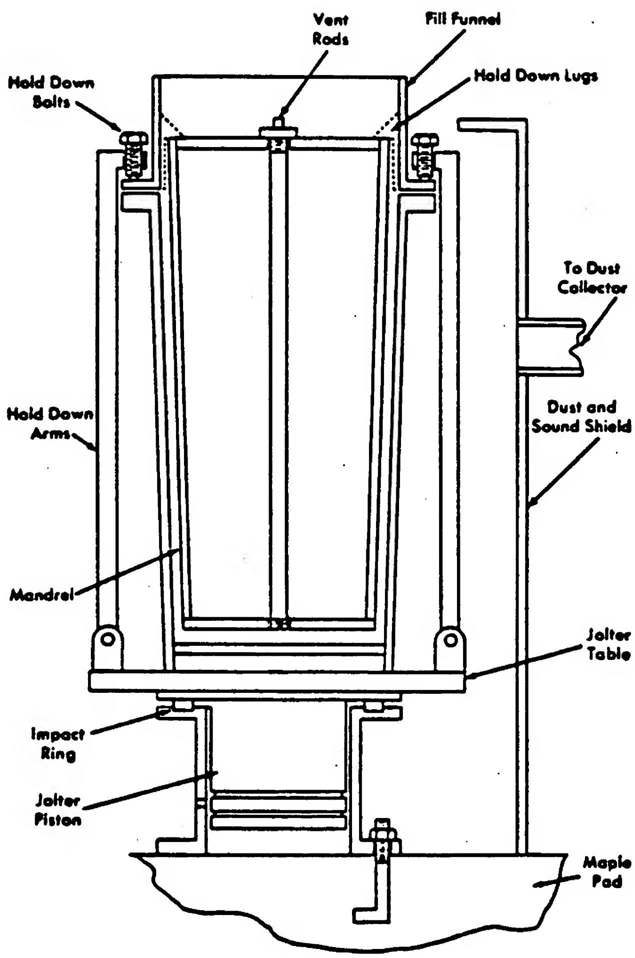
- Reg. Guide 8.15
- NUREG-0041
- ANSI-Z88.2

GREEN SALT REDUCTION TO METAL



Flowsheet for the production of uranium metal by the reduction of UF_4 with magnesium.

GREEN SALT REDUCTION

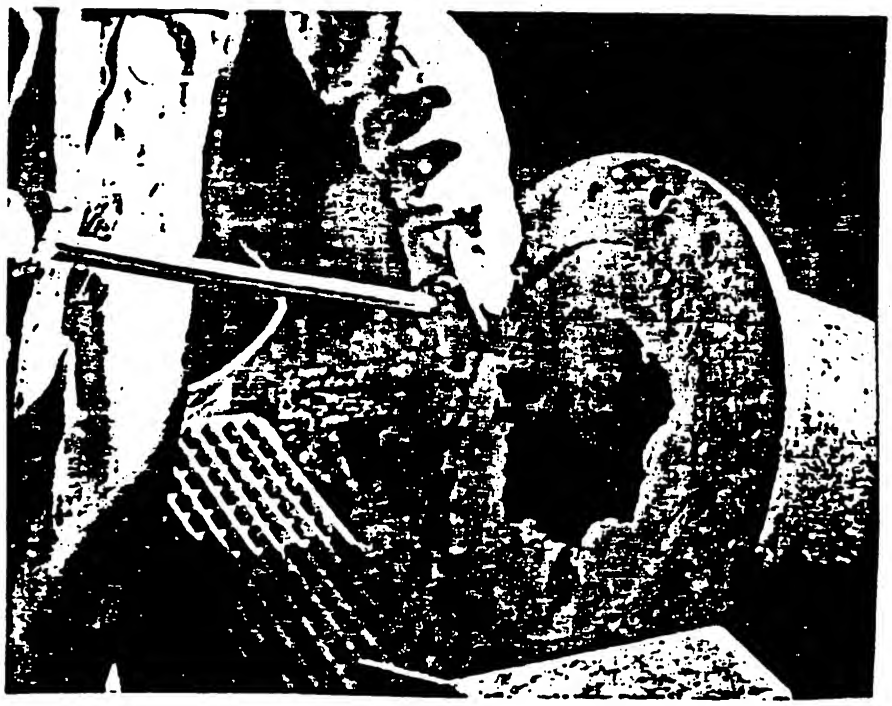


Equipment used for the formation of MgF_2 liner with funnel, mandrel, and bomb shell in place.

Thermite bomb

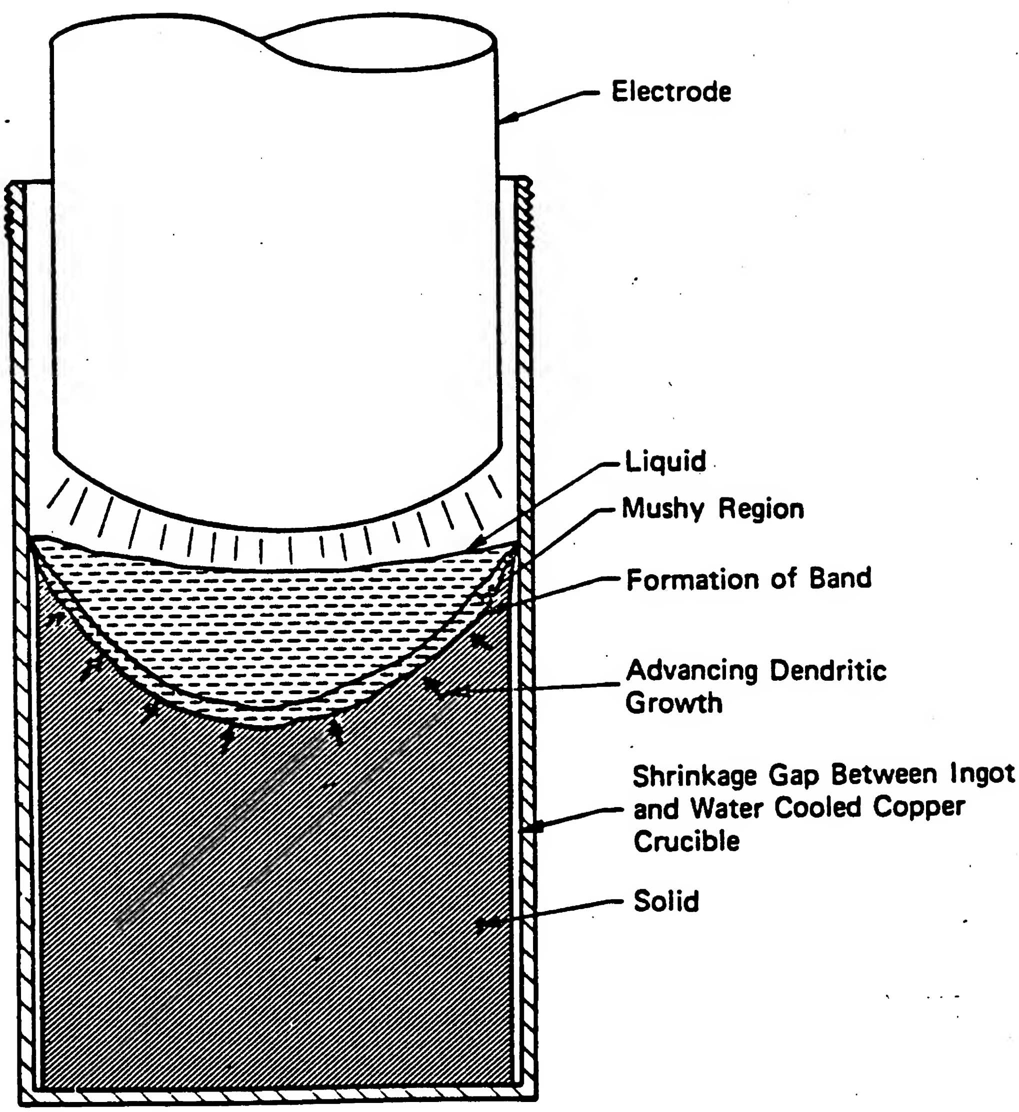
thermite reduction

GREEN SALT REDUCTION



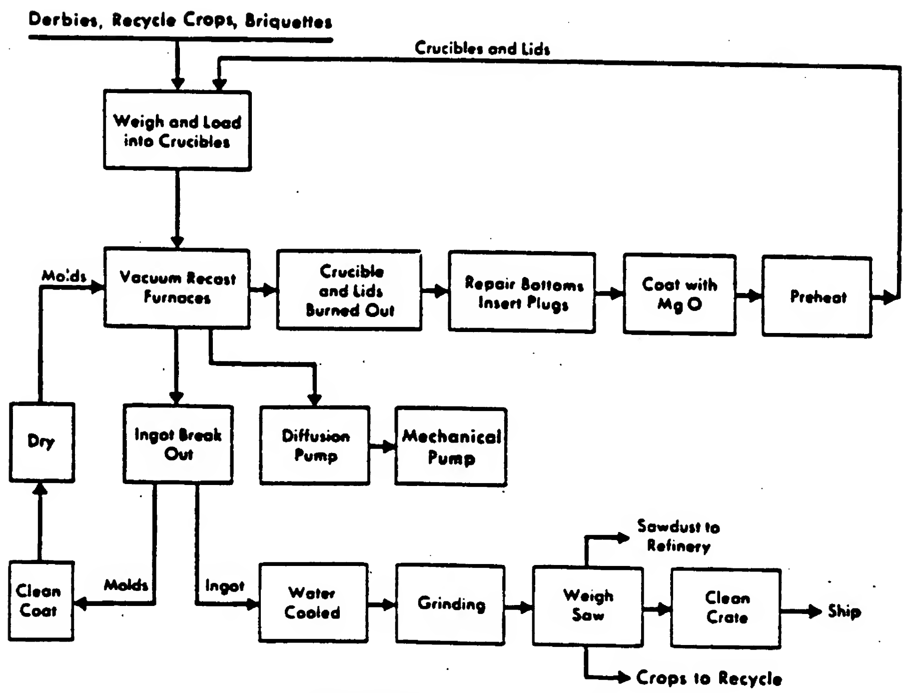
GREEN SALT REDUCTION

URANIUM RECASTING



Consumable D.C. Arc Melting

RECAST-PURIFICATION OF METAL



Flowsheet for casting of uranium metal.

CONVERSION OF DU DERBY TO COMPONENTS

- COPPER CLADDING OF EXTRUSION BILLET
  - LUBRICATION ENHANCEMENT
  - CONTAMINATION REDUCTION
  - GALLING PROBLEM AVOIDANCE
  - FLOW CHARACTERISTICS

CONVERSION OF DU DERBY TO ROD

- Mechanical Process
  - Preparation of Workpiece
  - Pre-Heat
  - Extrusion (Through a Die)
  - Forging (Through Mechanical or Hydraulic Press)
  - Swaging (Hammer Forging)
  - Survey and Clean-Up

HAZARDS ASSOCIATED WITH MECHANICAL PROCESS

- Exposure Rates (External)
- Oxidation (Contamination)
- Both Greatly Reduced by Copper Cladding
- Exposure Control/Evaluation
  - Protective Apparel
  - Dosimeters

CONVERSION OF DU ROD TO PENETRATOR

- MACHINING
- LATHING

POTENTIAL FIRE HAZARDS OF MACHINING/LATHING

- Filings and Fires
- Prevention (Water Based Coolant, Cutting Speed Adjustment)
- Fire-Fighting (Dry Argon Gas Envelope, Dry Powder Such as MeT-L-X)
- Interim Storage of Waste

HAZARDS ASSOCIATED WITH MACHINING/LATHING

- External Exposure
  - Whole Body, Hands, Eyes, Skin
- Exposure Control/Evaluation
  - Protective Apparel, Safety Glasses
  - Placement/Shielding of Material Not Being Worked
  - Controlled Entry Into Work Area
  - Direct Instrument Surveys and Dosimeters

HAZARDS ASSOCIATED WITH MACHINING/LATHING

- POTENTIAL INTERNAL EXPOSURE
  - INHALATION, INGESTION, INJECTION
- EXPOSURE CONTROL
  - AIR SAMPLING
  - RESPIRATORS/ENGINEERING CONTROLS
  - PROTECTIVE APPAREL - safety glasses. coveralls caps. rubbers
  - FREQUENT SURVEYS/DECONTAMINATION
  - CONTROLLED ENTRY INTO WORK AREA
  - STEP-OFF PADS/EXIT SURVEYS

INTERNAL EXPOSURE EVALUATION

- Lung and Whole Body Counting
- Urinalysis/Fecal Analysis
- Evaluation of Air Sample Data

HEALTH PHYSICS CONCERNS

PYROPHORICITY

WASTE MANAGEMENT — concentrate/contain
— dilute/dispose

LLW Limit
100 nano curies/gram

ins


95
95

PERSONNEL DU DOSIMETRY PROGRAM

- Program Goals and Requirements
  - Control of Occupational Exposure
  - Dose Assignment from Dosimetry Data
  - Accurate, Retrievable Data Storage

PERSONNEL DOSIMETER TYPES

- Photographic Film
- Thermoluminescent Dosimeters
- Self-Reading Pocket Dosimeters
- Pocket Alarming Dosimeters
- Finger Ring Dosimeters

PHOTOGRAPHIC FILM

- Principles of Operation
- Dosimeter Design
- Processing Techniques
- Interpretation and Calibration
- Advantages and Limitations

THERMOLUMINESCENT DOSIMETERS (TLD)

- Principles of Operation
- Dosimeter Design
- Processing
- Interpretation and Calibration
- Advantages and Limitations

SELF-READER AND POCKET ALARMING DOSIMETERS

- Principles of Operation
  - Self-Reading Pencils
  - Pocket Alarming Dosimeters
- Interpretation and Calibration
- Advantages and Limitations

IMPORTANT FACTORS FOR ACCURATE DOSE ASSIGNMENT

- Proper Dosimeter Placement on Personnel
- Identify Energy Response
- Proper Calibration/NBS Traceability
- QA of Processing Techniques
- QA of Record Keeping System

RADIATION DETECTION INSTRUMENTS

Dose Rate Instruments

Ionization Chambers

Energy Compensated GM Detectors

RADIATION DETECTION INSTRUMENTS

SURVEY INSTRUMENTS:

- ALPHA PROPORTIONAL COUNTERS
- SCINTILLATION DETECTORS
- GEIGER-MUELLER DETECTORS

RADIATION DETECTION INSTRUMENTS

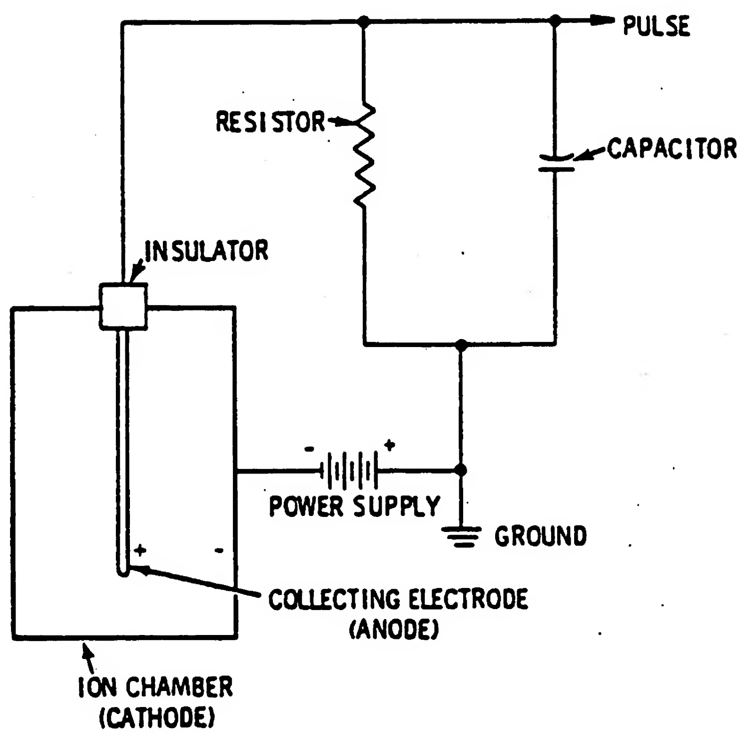
LABORATORY COUNTERS

CALIBRATION

PERFORMANCE CHECKS

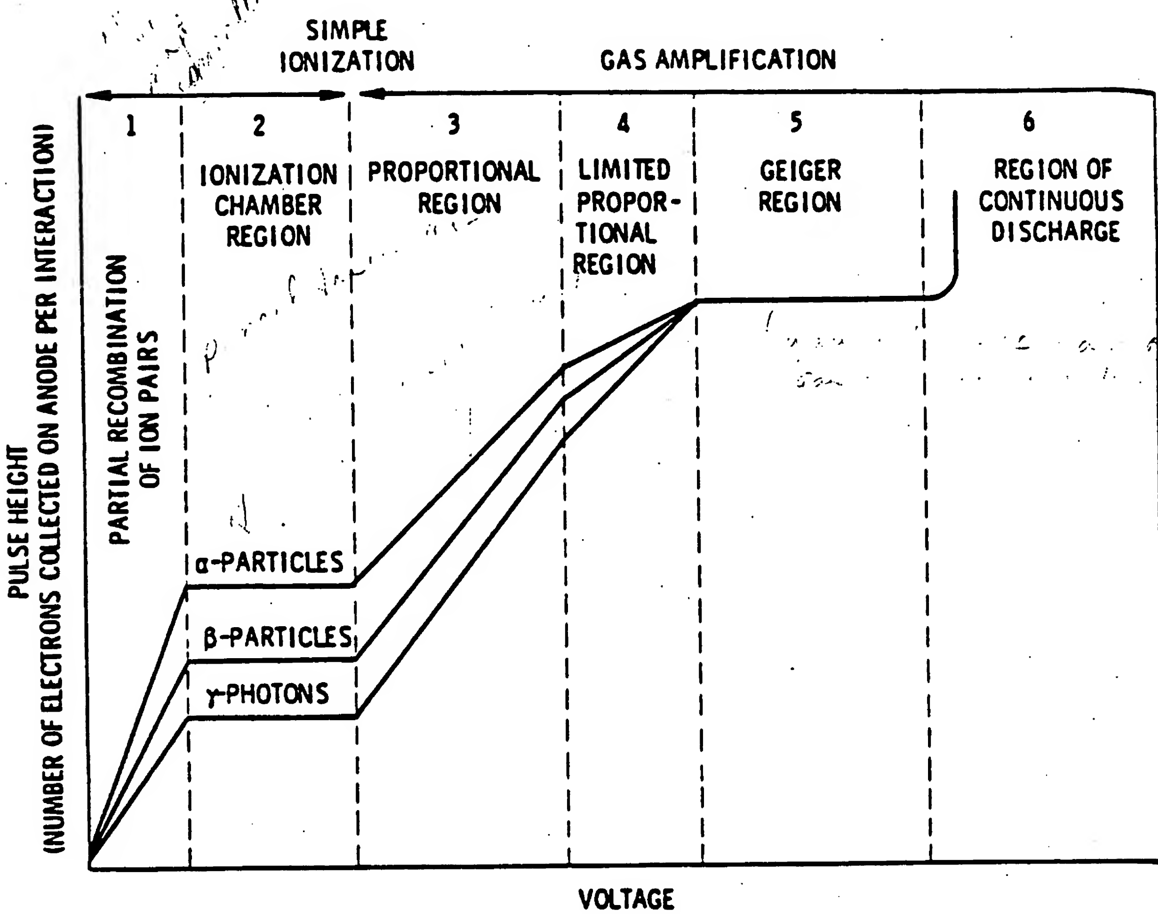
RECORDS

QUALITY ASSURANCE



Simplified Version of a Chamber Used to Collect Ions

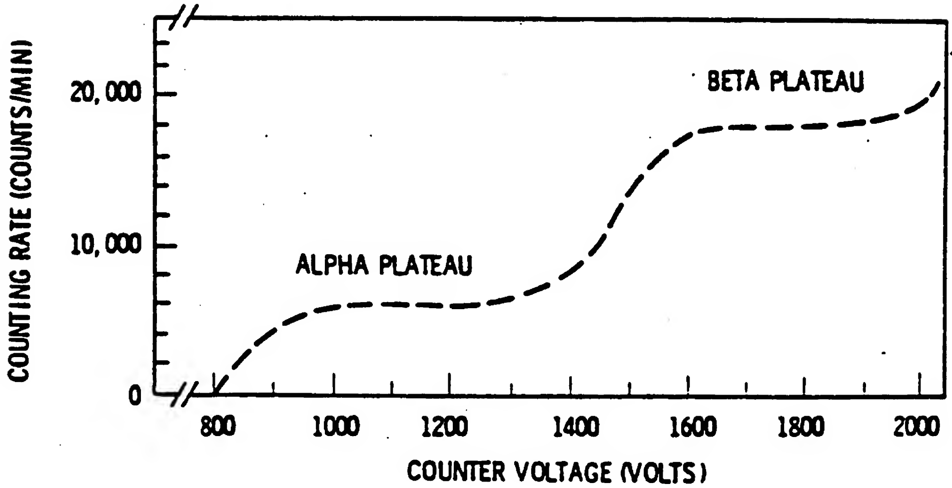
RADIATION DETECTION INSTRUMENTS



Relationship Between Applied Voltage and the Number of Electrons Collected on the Anode

Ionization chamber will NOT saturate

Scintillation instruments can be made to ... Out ...



Plateaus for Typical Proportional Counter

RADIATION SURVEY INSTRUMENTS

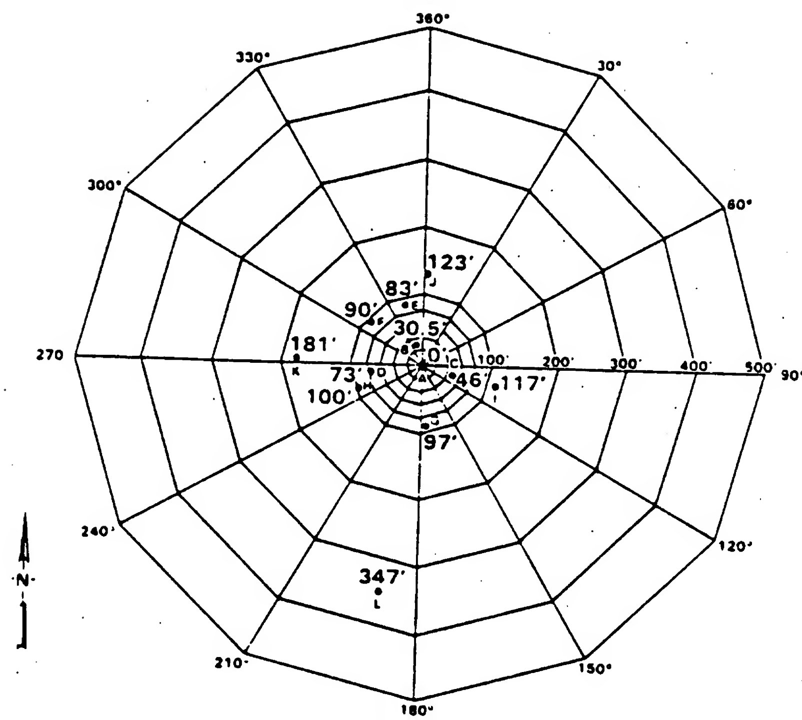
Detector	Types of Radiation Measured	Typical Full Scale Readings	Use	Minimum Energy Measured	Directional Dependence	Advantages	Possible Disadvantages
Scintillation counter	Beta, x, gamma, neutrons	0.02 mR/h to 20 mR/h	Survey	20 keV for x rays. Variable for betas	Low for x or gamma	1. High sensitivity 2. Rapid response	1. Fragile 2. Relatively expensive
Geiger-Muller counter	Beta, x, gamma	0.2 to 20 mR/h or 800 to 80,000 counts/min	Survey	20 keV for x rays. 150 keV for betas	Low for x or gamma	Rapid response	1. Strong energy dependence 2. Possible paralysis of response at high count rates or exposure rates 3. Limited range
Ionization chamber	Beta, x, gamma	3 mR/h to 500 R/h	Survey	20 keV for x rays. Variable for betas	Low for x or gamma	1. Low energy dependence 2. Accurate measurements	1. Relatively low sensitivity 2. May be slow to respond
Proportional	Alpha, Beta	500,000 cpm	Survey for alpha contamination	Depends on window thickness	High	1. Special probes for alpha detection or beta detection 2. Can count alphas without interference from β's or γ's	1. Slow response 2. Fragile window
Alpha Scintillation counter	Alpha	100 to 10,000 alpha/min	Survey	Variable	High	Designed especially for alpha particles	1. Slow response 2. Fragile window
Pocket ionization chamber and dosimeter	X, gamma	200 mR to 200 R	Survey and monitoring	50 keV	Low	1. Relatively inexpensive 2. Gives estimate of integrated dose 3. Small size	1. Subject to accidental discharge

FIRE HAZARDS OF DU MUNITIONS

- Review of DU Penetrator Ammunition
  - Favorable Penetrating Characteristics
  - Relative Scarcity of Competitive Metal (Tungsten)
  - High Availability of DU

EXPERIMENTAL DATA FROM HEAT TEST (XM774)

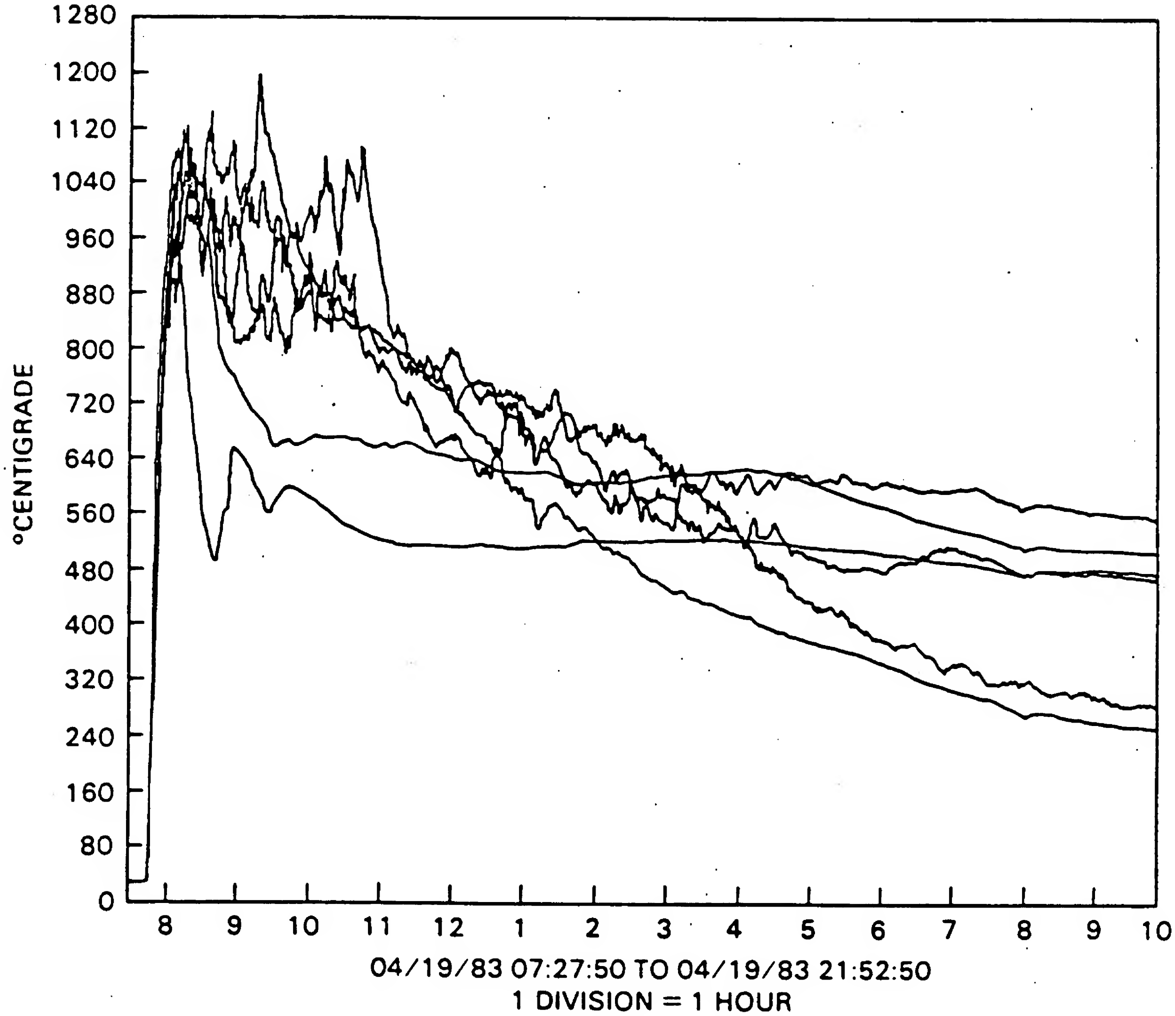
- TEST DESCRIPTION
- PROPELLANT IGNITION (METAL SHELL CASING)
- DISTRIBUTION OF DISRUPTED ROUNDS
- EFFECTS OF FIRE ON DU PENETRATORS
- RADIOLOGICAL HAZARDS IN CLOSE PROXIMITY
- RADIOLOGICAL HAZARDS DOWNWIND
- RECOVERY PERCENTAGES OF ORIGINAL DU WEIGHT



Schematic of Test Grid Indicating Position and Distances from Ground Zero of Projectiles After Burn Test

EXPERIMENTAL DATA FROM HEAT TESTS (XM829)

- Test Description
- Propellant Ignition (Combustible Casing)
- Disposition of Rounds
- Effects of Fire on DU Penetrators
  - Remnants
  - Oxidation
- Radiological Hazards in Close Proximity
- Radiological Hazards Downwind
- Recovery Percentages of Original DU Weight



External Heat Test Time Vs. Temperature

CONCLUSIONS OF XM774 AND XM829 HEAT TESTS

- FIREFIGHTING VERSUS TIME

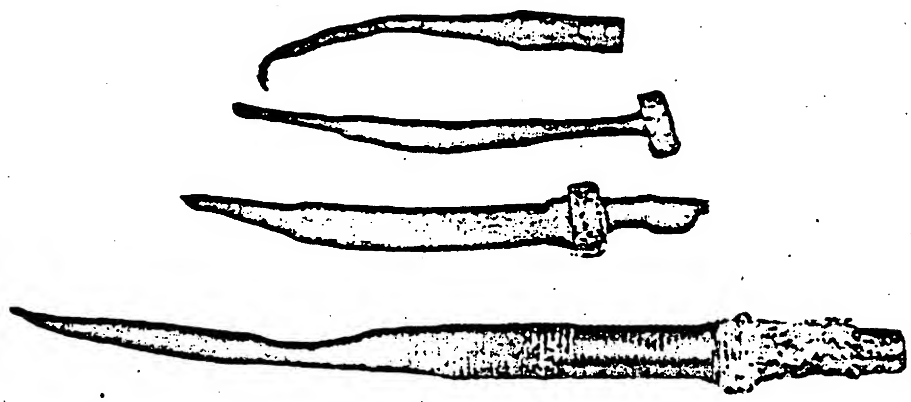
  fielded

  - XM774 105mm
  - XM829 120mm

    not fielded

- RADIOLOGICAL CONTROL SUGGESTIONS DURING AND FOLLOWING FIRE

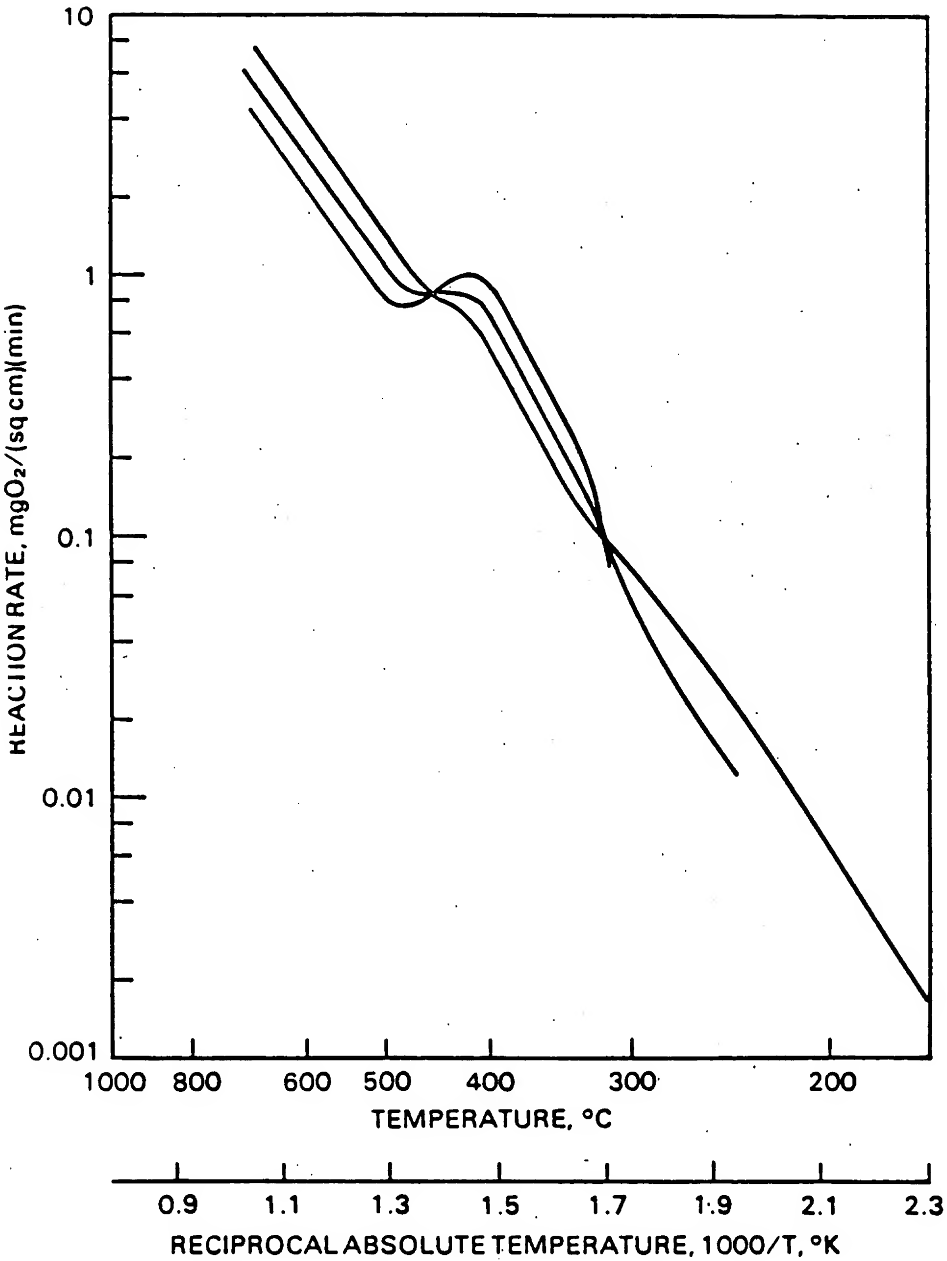
  - DURING DU FIRE
  - DURING CLEANUP OPERATIONS recovered only 60%



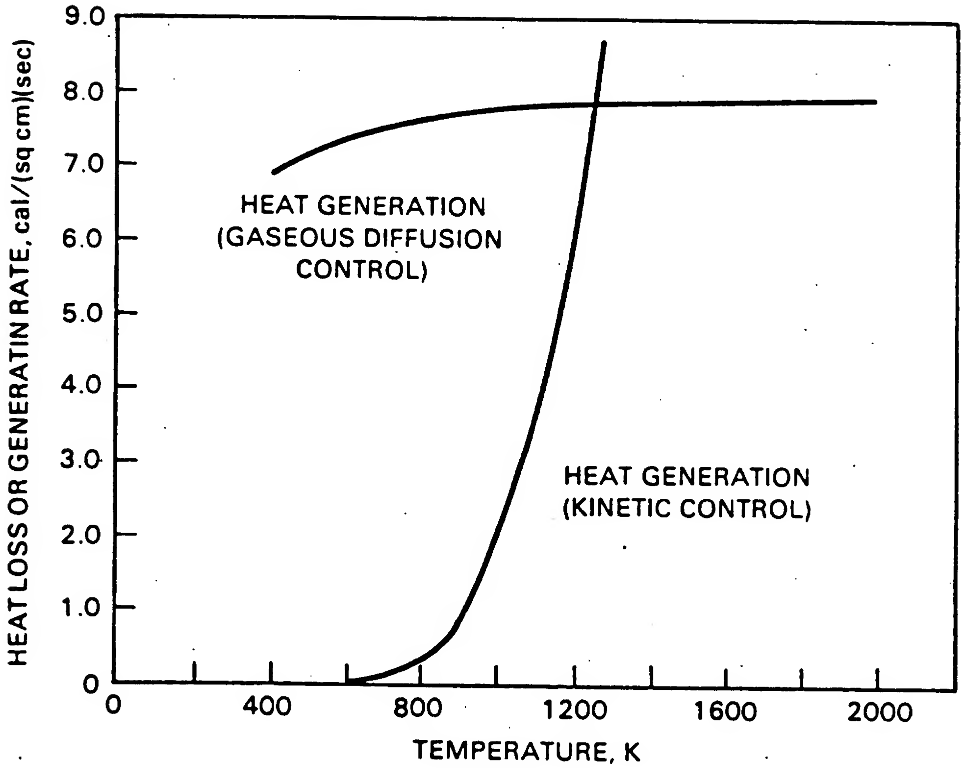
Remnants of Projectiles Recovered After Fire

FINDINGS OF LOS ALAMOS HEAT TEST

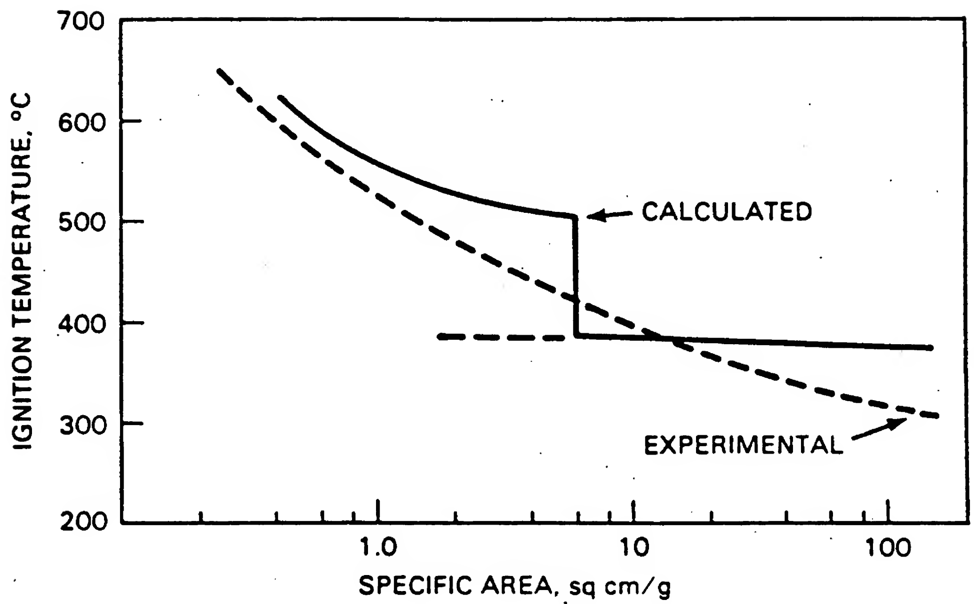
- TEST CONDITIONS
- CONCLUSIONS



Oxidation Rates of Uranium in Air and Oxygen
(L. Baker, Jr. and J. D. Bingle 1966)



Effect of Temperature on Heat Generation Rates
(Leibowitz et al. 1962)



Dependence of Uranium Ignition on Specific Area (L. Baker, Jr., J. G. Schnizlein and J. D. Bingle 1966)

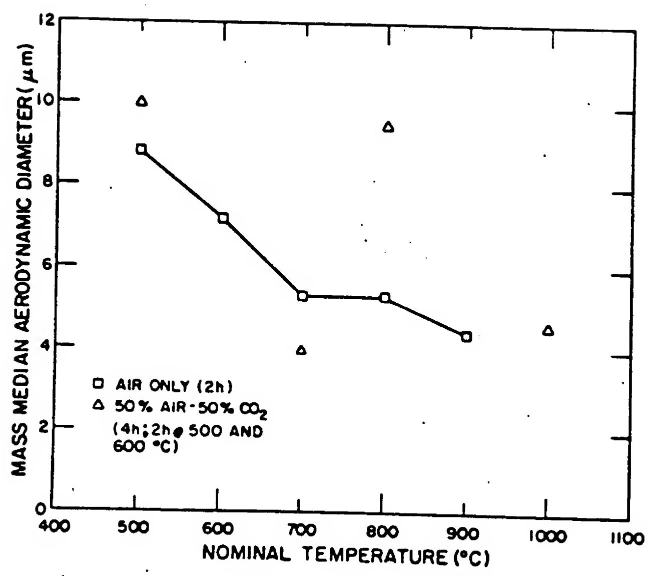


Fig. 21.
Size of aerosol <10-μm as a function of temperature.

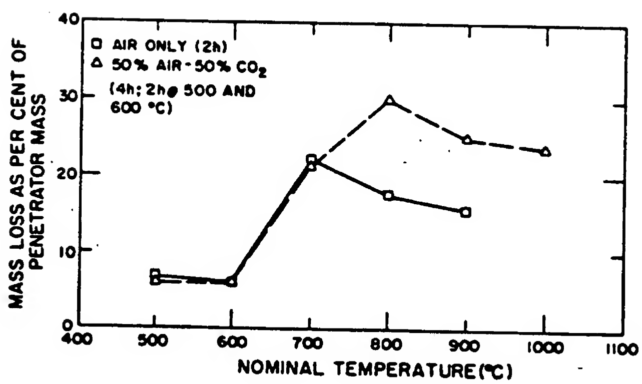


Fig. 10.
Oxidation as a function of temperature.

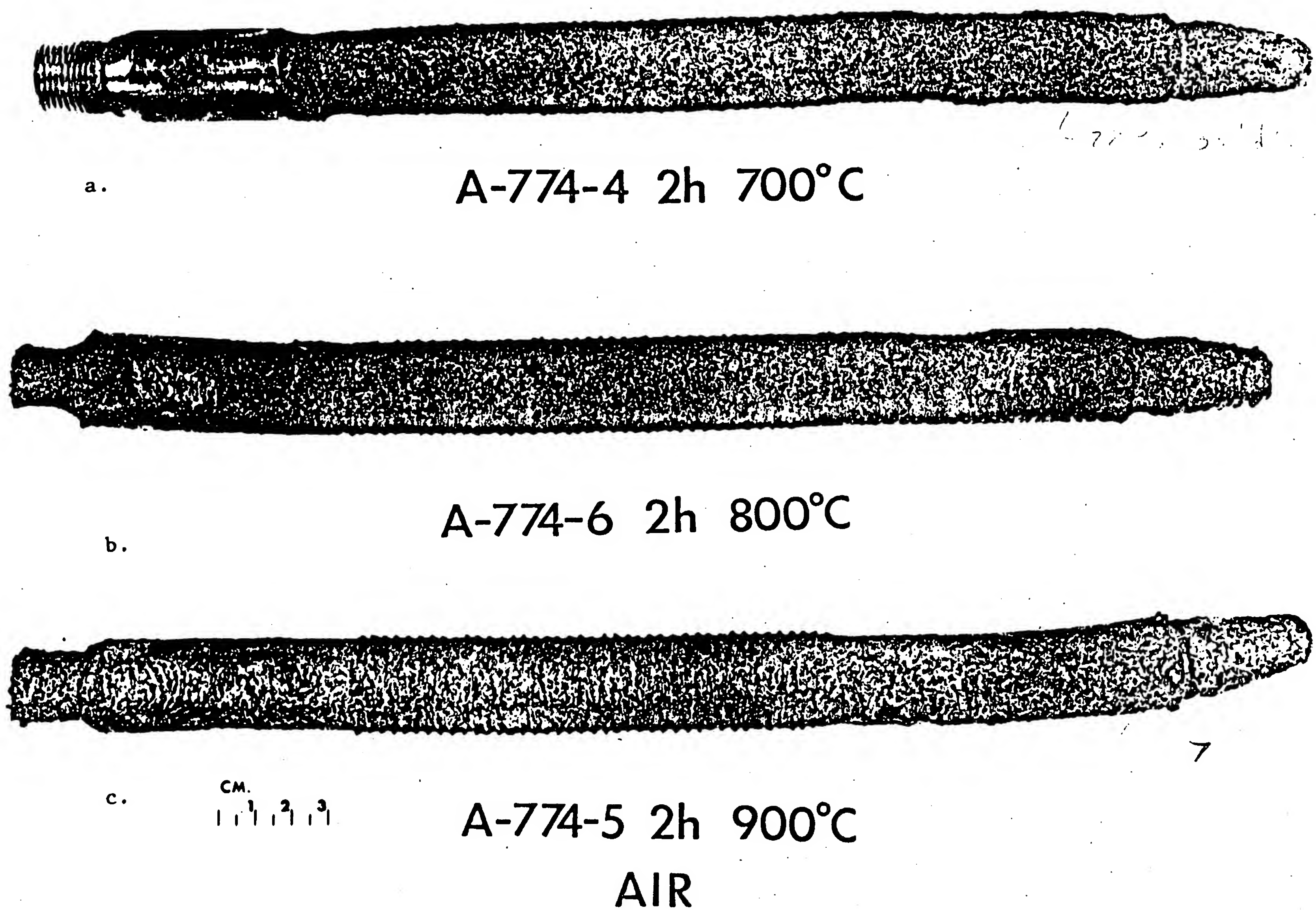


Fig. 13.
Penetrators after exposure to air at the listed temperatures.

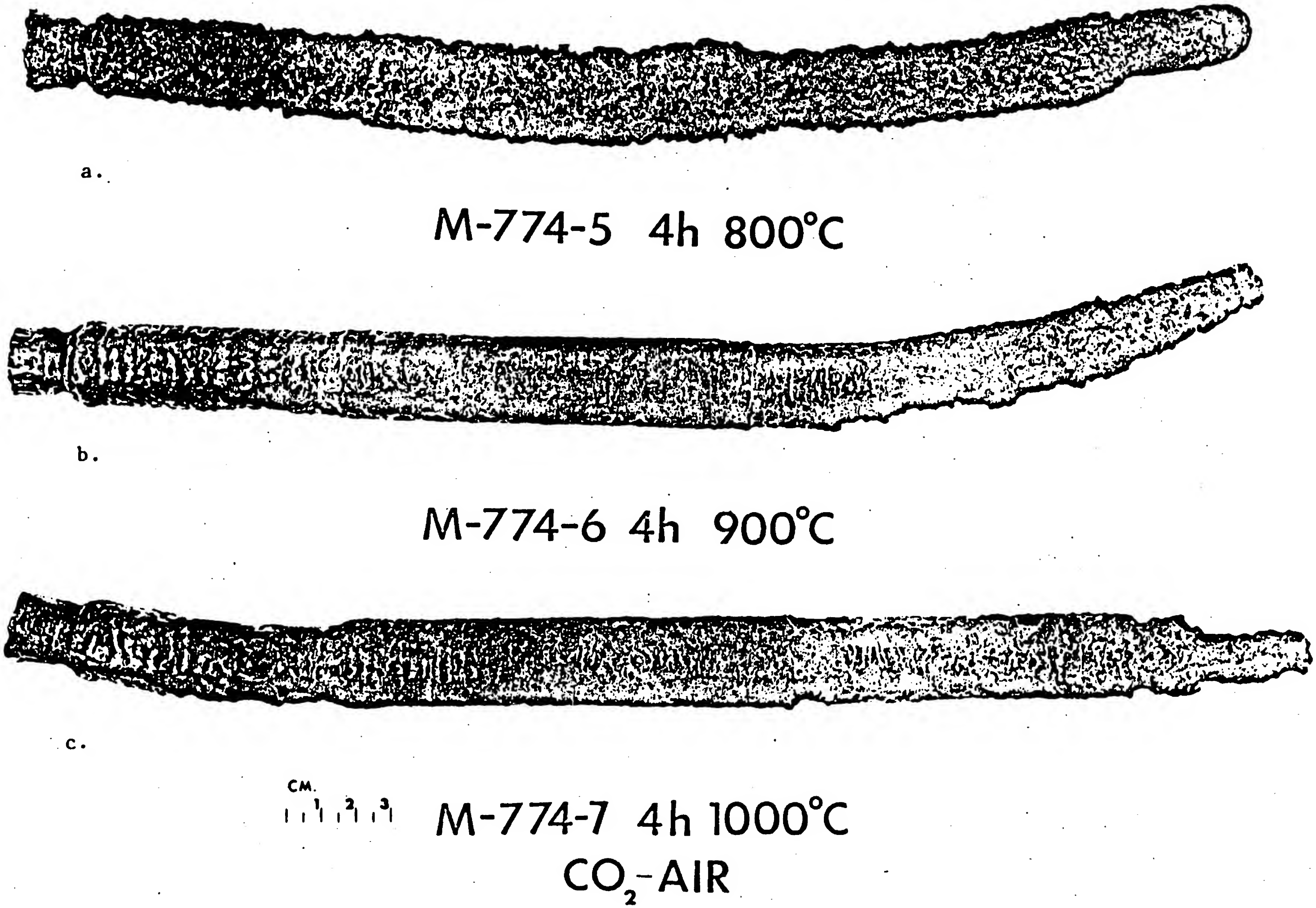


Fig. 15.

Penetrators exposed to CO_2-air mixture at the listed temperature.

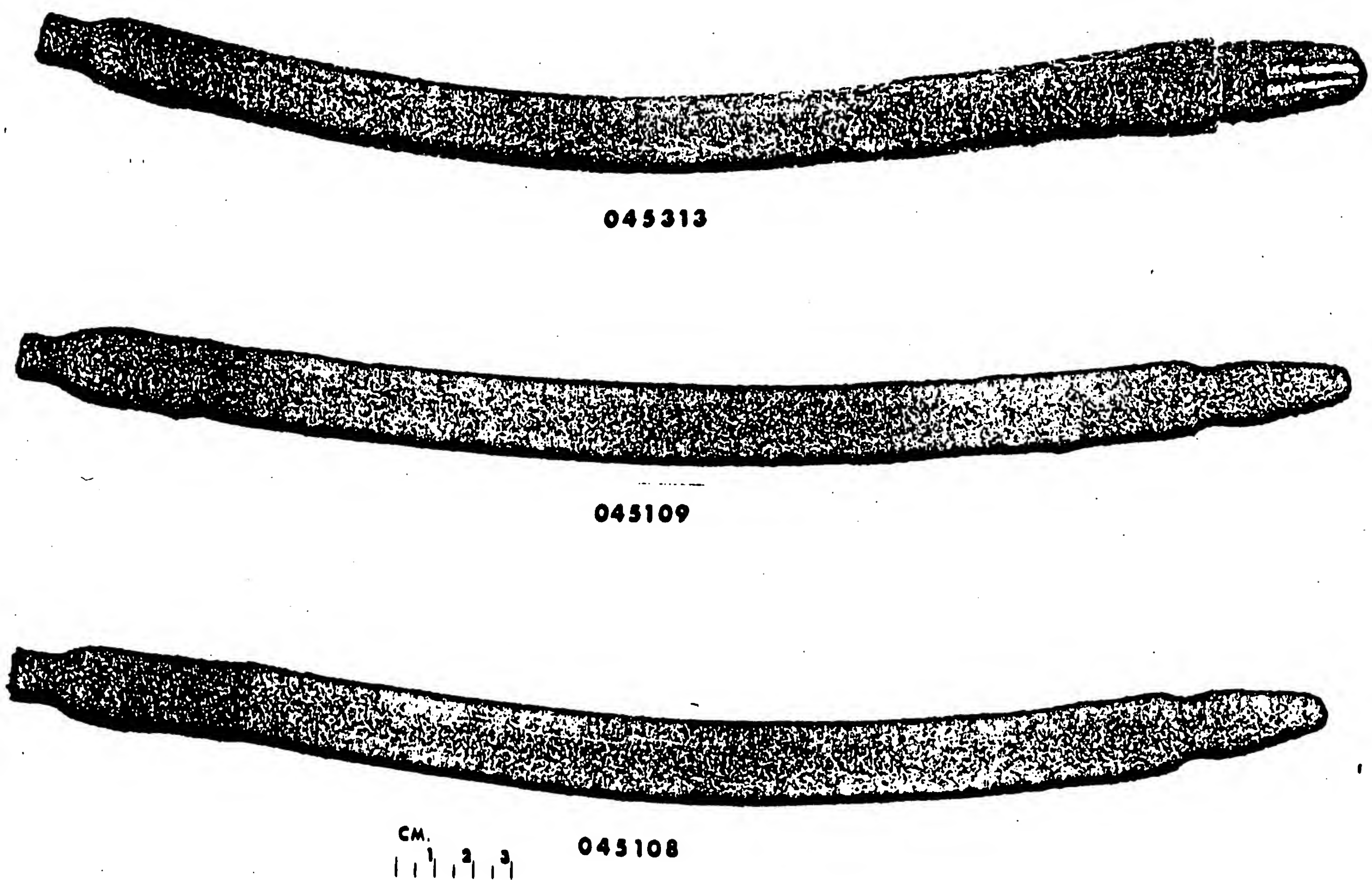


Fig. 9.

Burn 4 penetrators after cleaning by wire brushing.

DEMILITARIZATION OF DU AMMUNITION

- Large Calibre (75mm - 155mm)
- Small Calibre (10mm - 30mm)

DU MUNITION STORAGE

- PERIODIC AREA SURVEYS — repeat after 150 days (5 [illegible] lives) to look at [illegible] equilibrium & possible [illegible] of radon daughters
  - EXPOSURE RATES
  - CONTAMINATION
    (smear survey — 100 cm^2 (10x10)
- POSTING

FIRE IMPLICATIONS FROM STORAGE OF DU AMMUNITION

- IGLOO FIRE
  - UNSUSTAINED
  - SUSTAINED
- RESPONSE
- METEROLOGY CONSIDERATIONS
- CONTROLS/EVALUATIONS

TABLE I FOR STABILITY CLASS B

CONCENTRATION-TIME FACTOR

Source Strength	25 mg-hr/m**3	8 mg-hr/m**3	2.5 mg-hr/m**3
	Distances		
kg-s/m	km	km	km
100	0.144	0.255	0.454
200	0.206	0.36	0.628
500	0.323	0.566	0.936
800	0.405	0.693	1.124
1000	0.454	0.758	1.224
2000	0.627	1.02	1.591
5000	0.936	1.452	2.227
8000	1.117	1.74	2.607
10000	1.219	1.893	2.809
20000	1.585	2.4	3.569
50000	2.226	3.268	5.066
80000	2.609	3.841	6.196
100000	2.796	4.189	6.77

TABLE II FOR STABILITY CLASS D

CONCENTRATION-TIME FACTOR

Source Strength	25 mg-hr/m**3	8 mg-hr/m**3	2.5 mg-hr/m**3
	Distances		
kg-s/m	km	km	km
100	0.217	0.392	0.777
200	0.321	0.603	1.149
500	0.532	0.994	1.956
800	0.696	1.308	2.528
1000	0.781	1.49	2.843
2000	1.146	2.204	4.247
5000	1.95	3.664	7.227
8000	2.512	4.854	9.505
10000	2.828	5.518	10.804
20000	4.253	8.311	16.353
50000	7.203	14.144	28.336
80000	9.514	18.741	36.544
100000	10.867	21.42	41.441

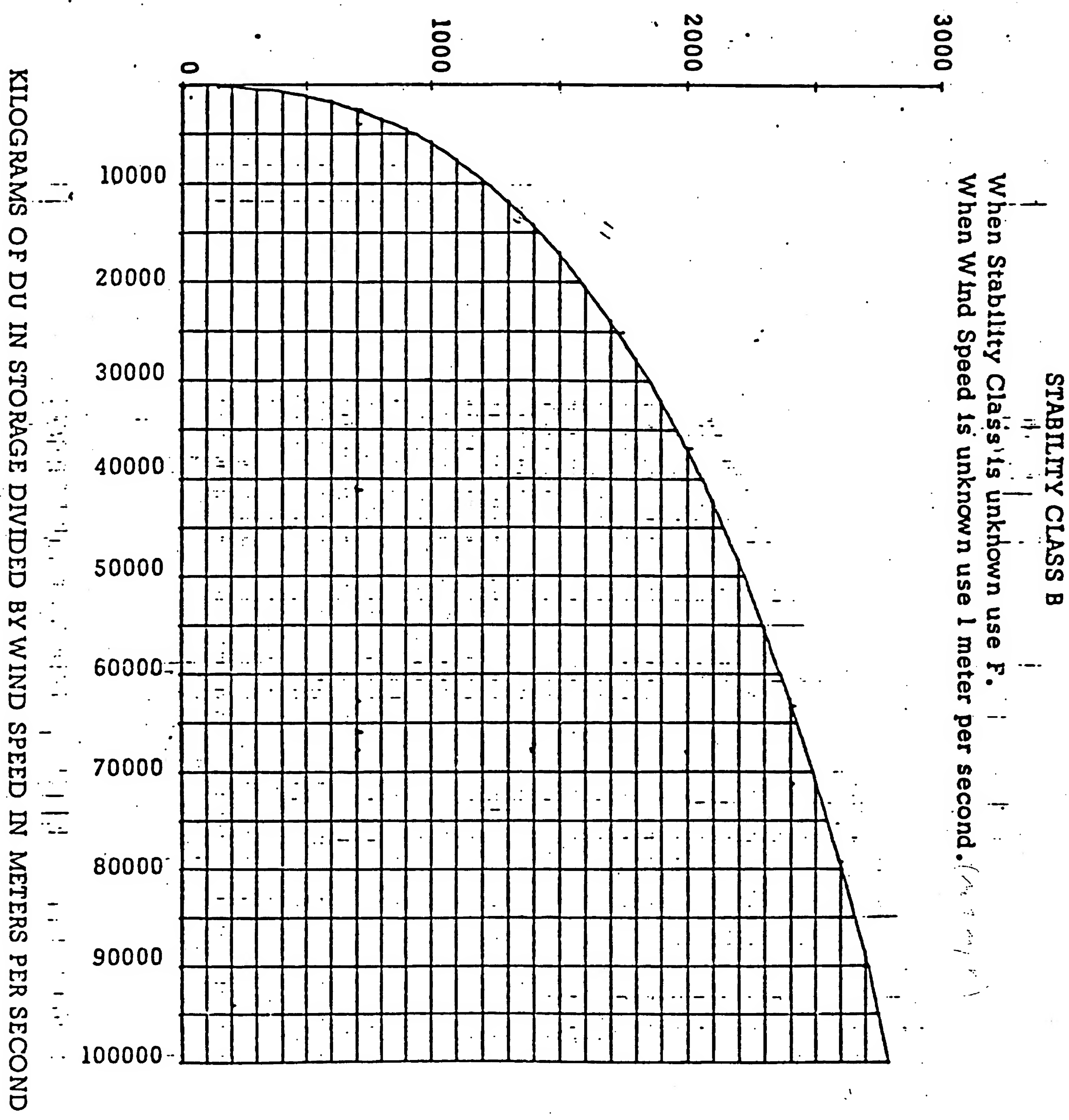
TABLE III FOR STABILITY CLASS F

CONCENTRATION-TIME FACTOR

Source Strength	25 mg-hr/m**3	8 mg-hr/m**3	2.5 mg-hr/m**3
	Distances		
kg-s/m	km	km	km
100	0.356	0.654	1.252
200	0.516	0.949	1.895
500	0.834	1.637	3.14
800	1.095	2.149	4.299
1000	1.248	2.417	4.912
2000	1.896	3.663	7.92
5000	3.133	6.58	14.384
8000	4.289	9.13	19.555
10000	4.916	10.555	22.663
20000	7.897	16.666	35.9
50000	14.441	30.387	65.427
80000	19.61	41.598	87.065
100000	22.727	47.986	100.648

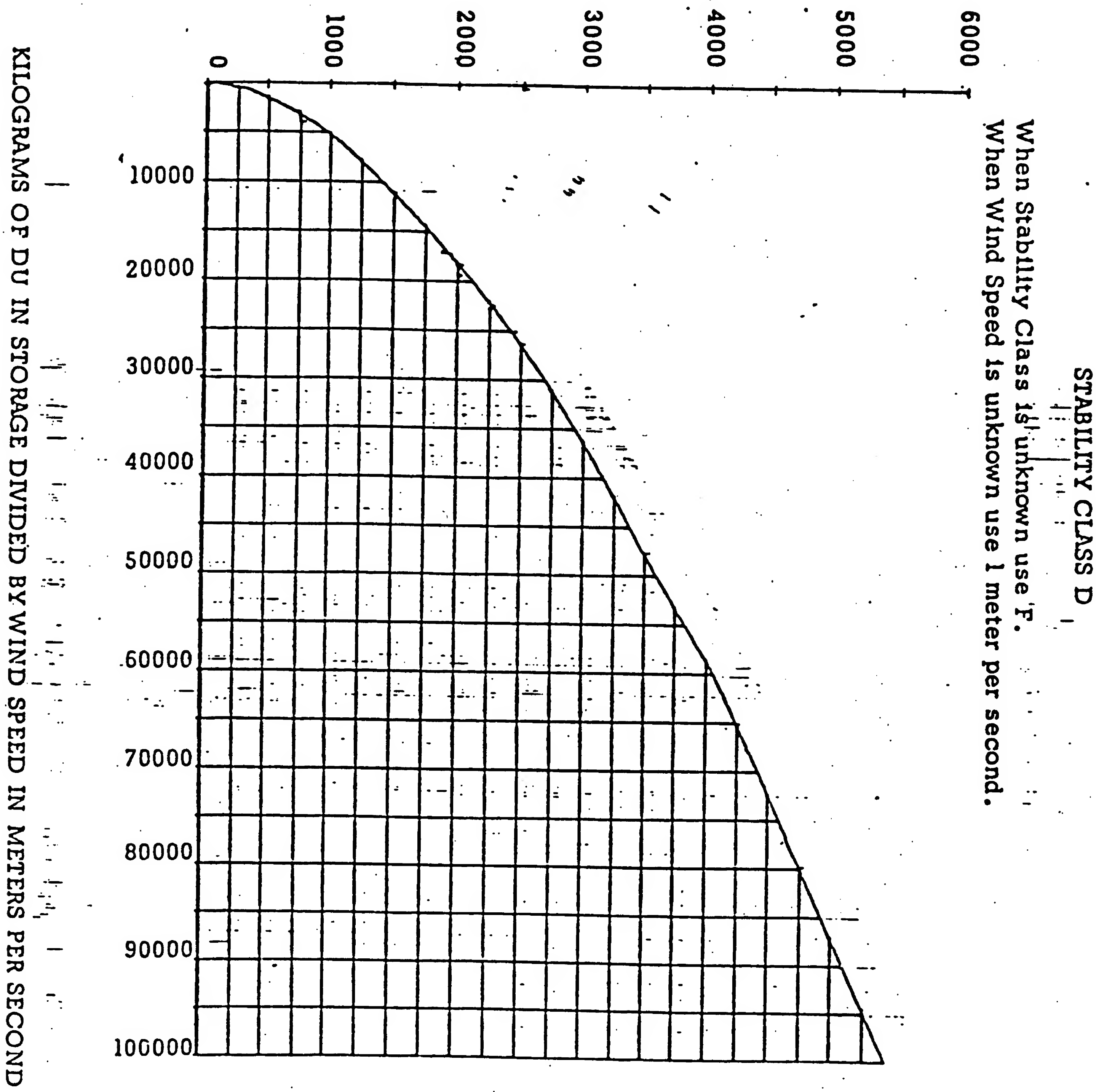
CONTROL BOUNDARY FOR FIRES

METERS



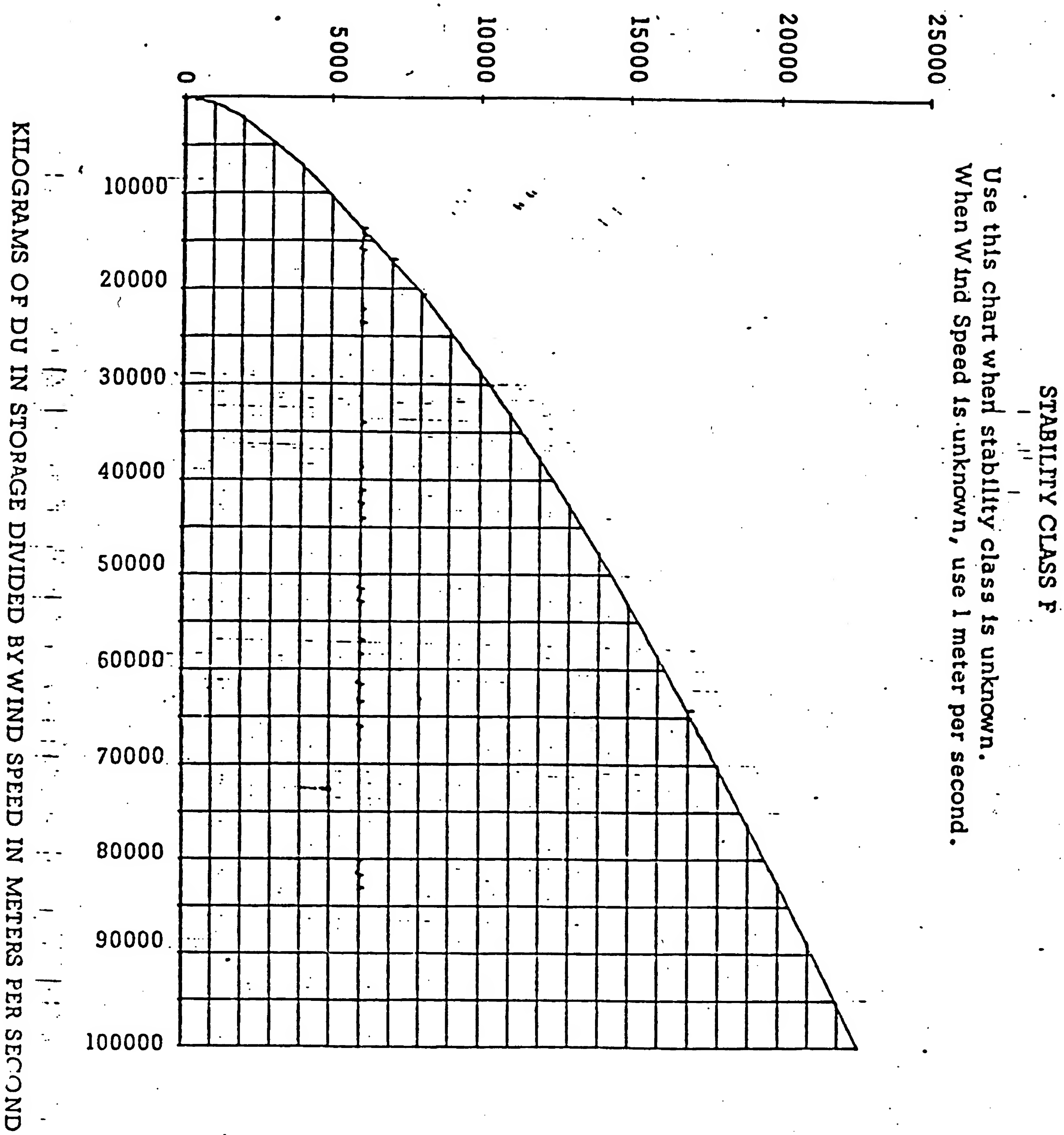
CONTROL BOUNDARY FOR FIRES

METERS

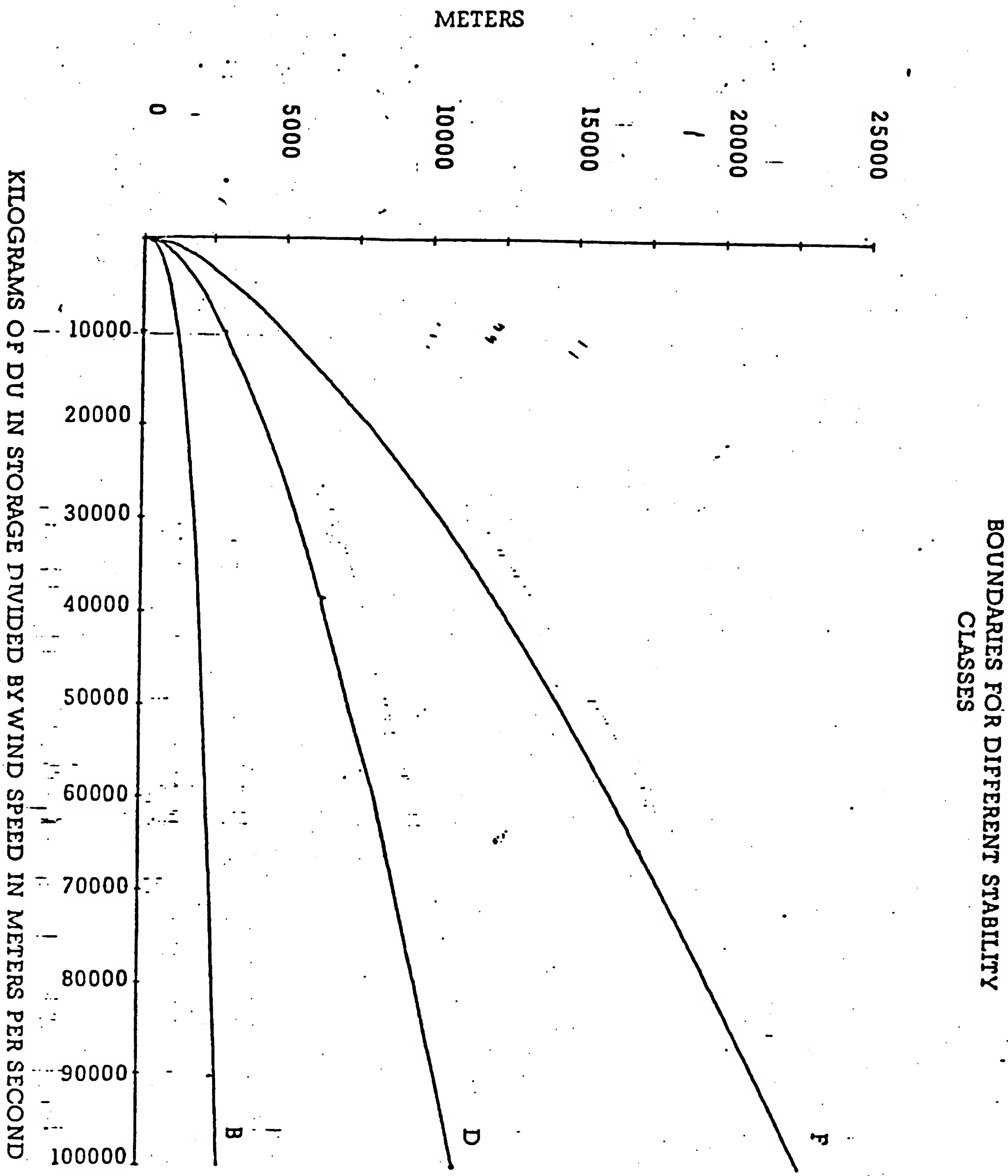


CONTROL BOUNDARIES FOR FIRES

METERS

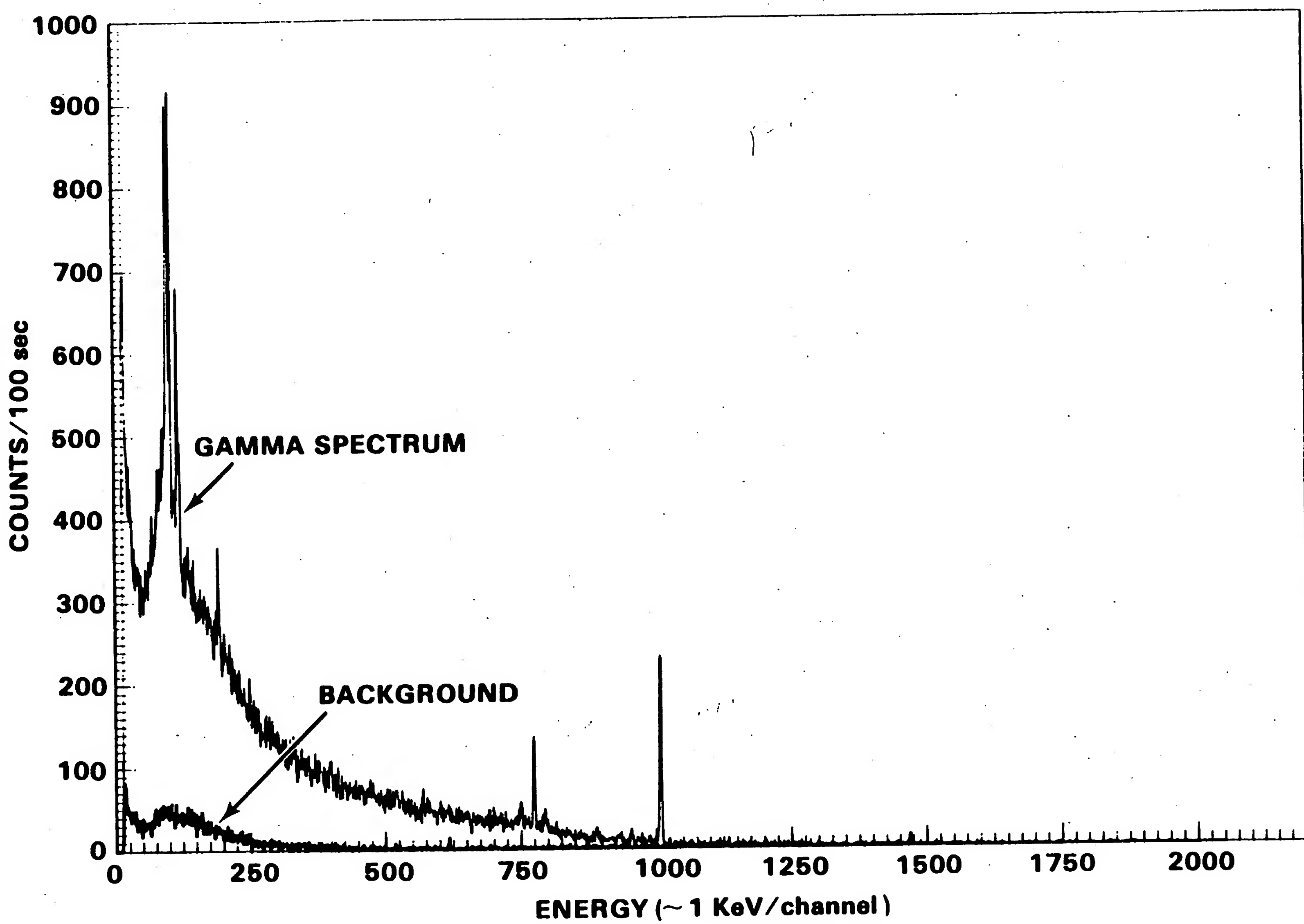


CONTROL BOUNDARIES FOR FIRES

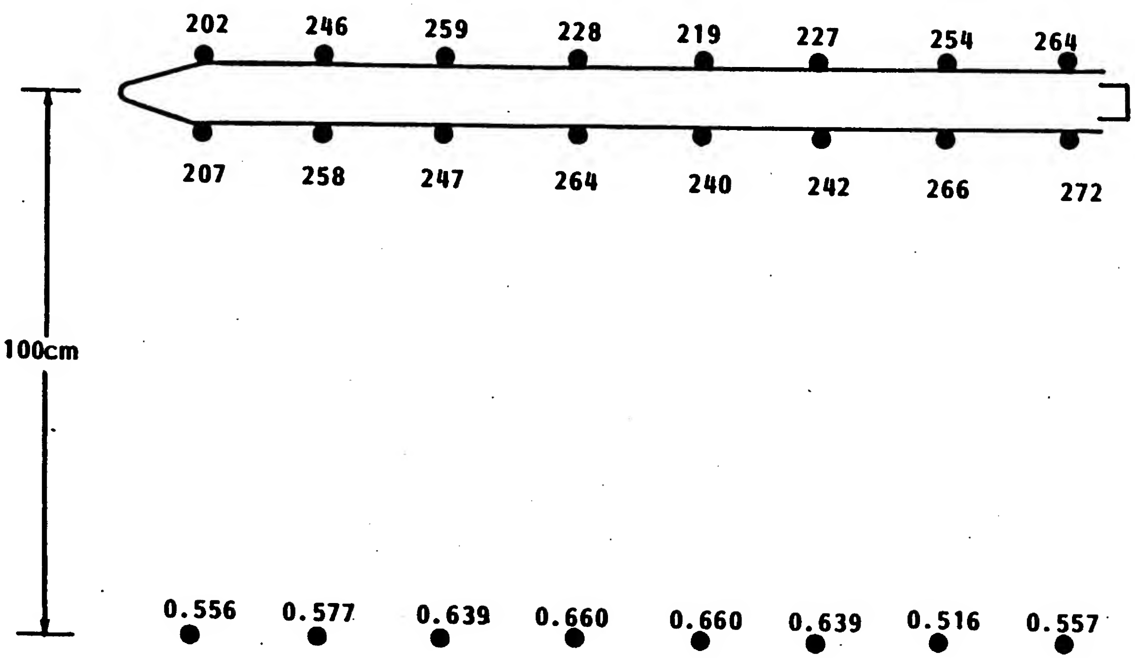


DU MUNITION TRANSPORT

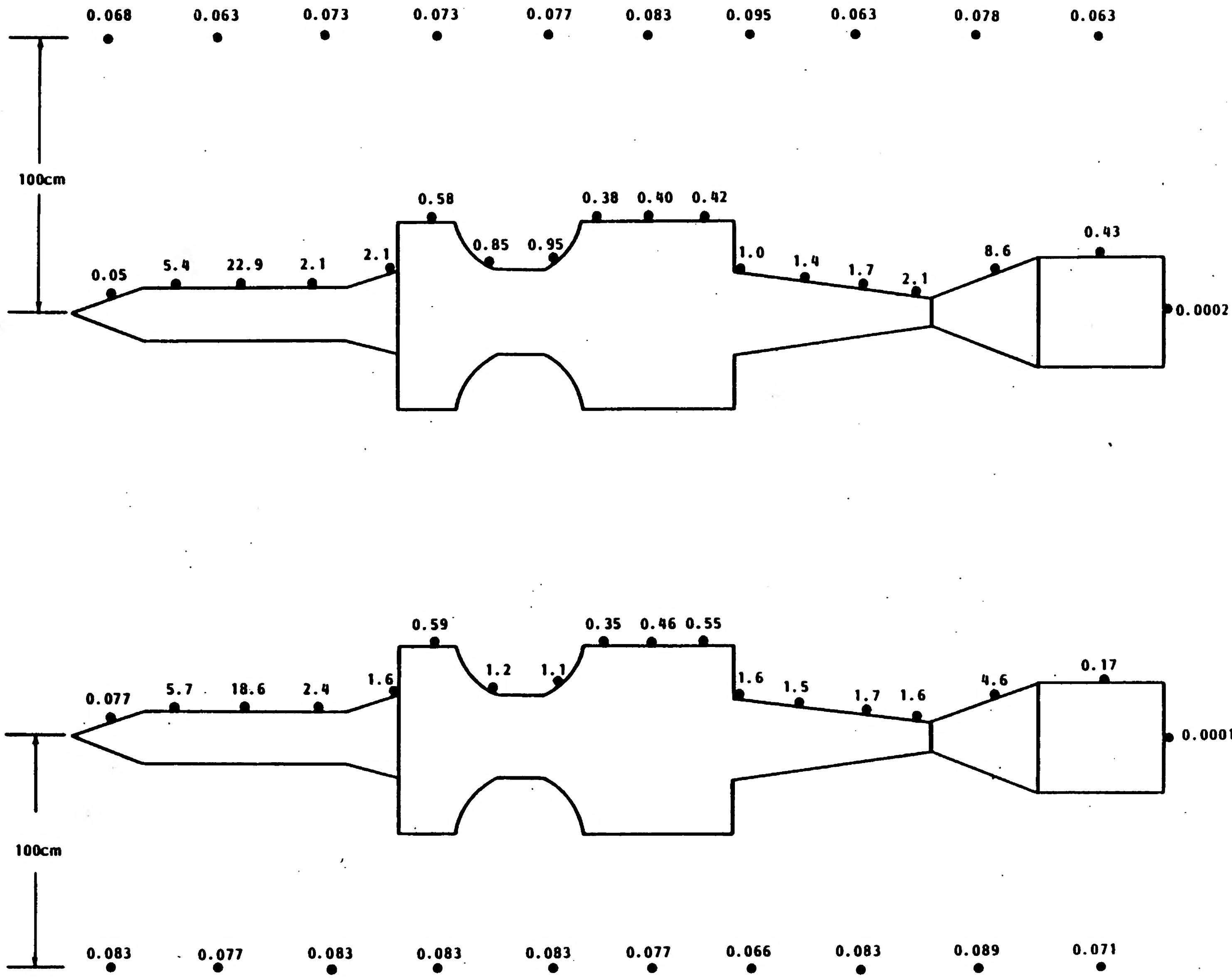
- Compliance With Regulations
- Shipment Surveys (Proper Instrument Selection)
  - Exposure Rates
  - Contamination
- Shipping Papers in Order
- Ensure That Recepient is Authorized to Receive Shipment



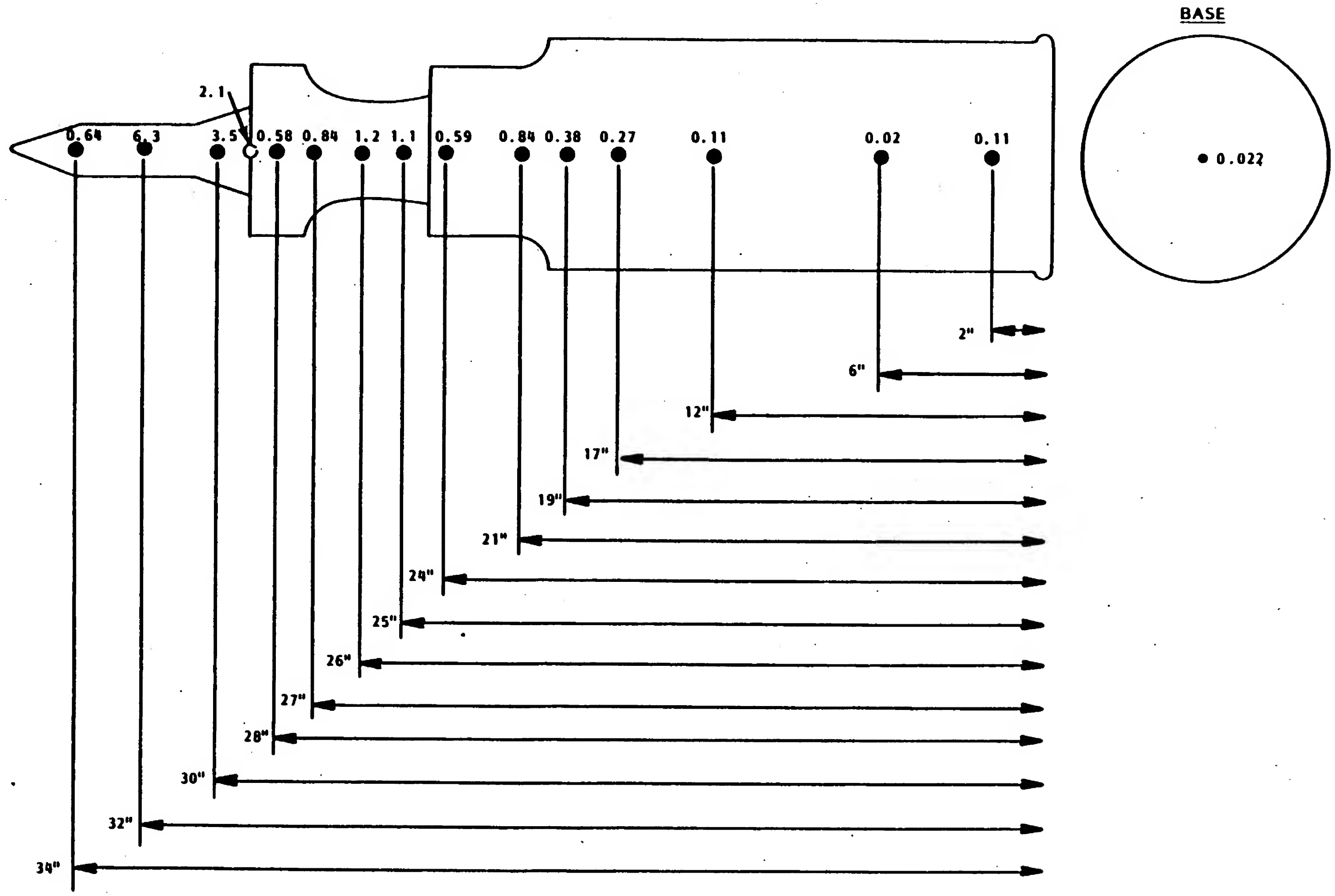
Typical Gamma Spectrum from an Assembled XM829 Projectile



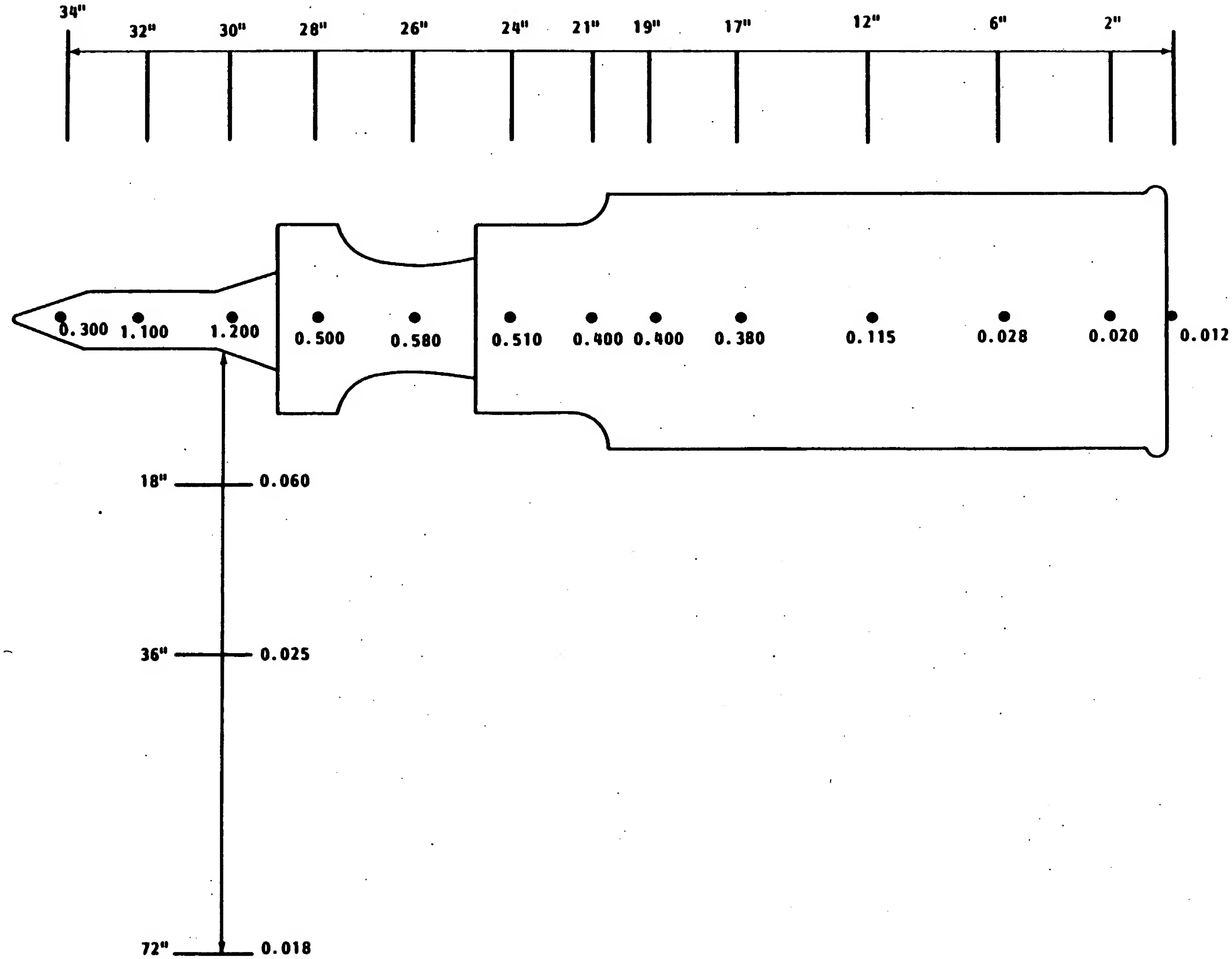
TLD Measurements (mrem/hr) of Bare Penetrator



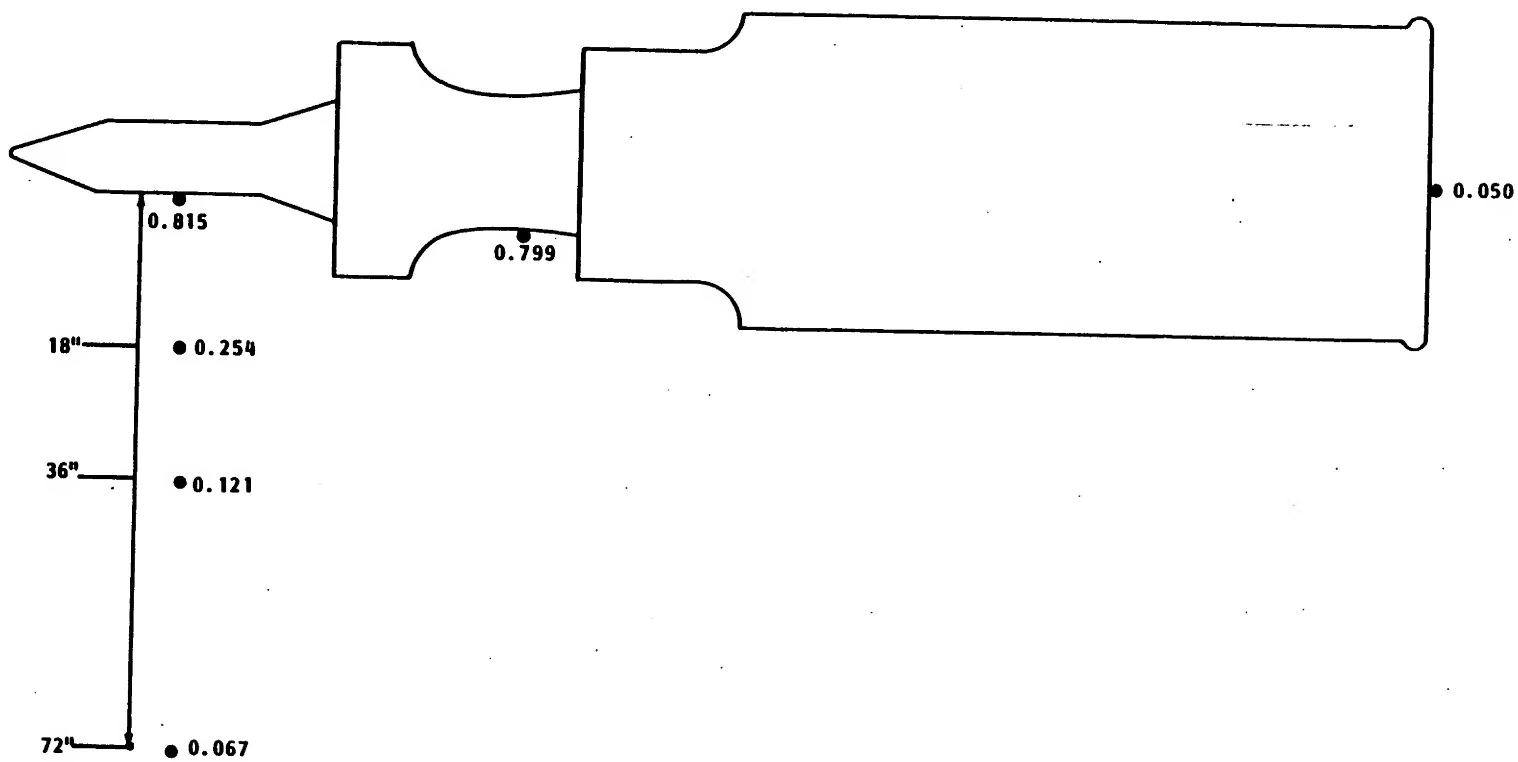
TLD Measurements (mR/hr) of Two individual Projectiles



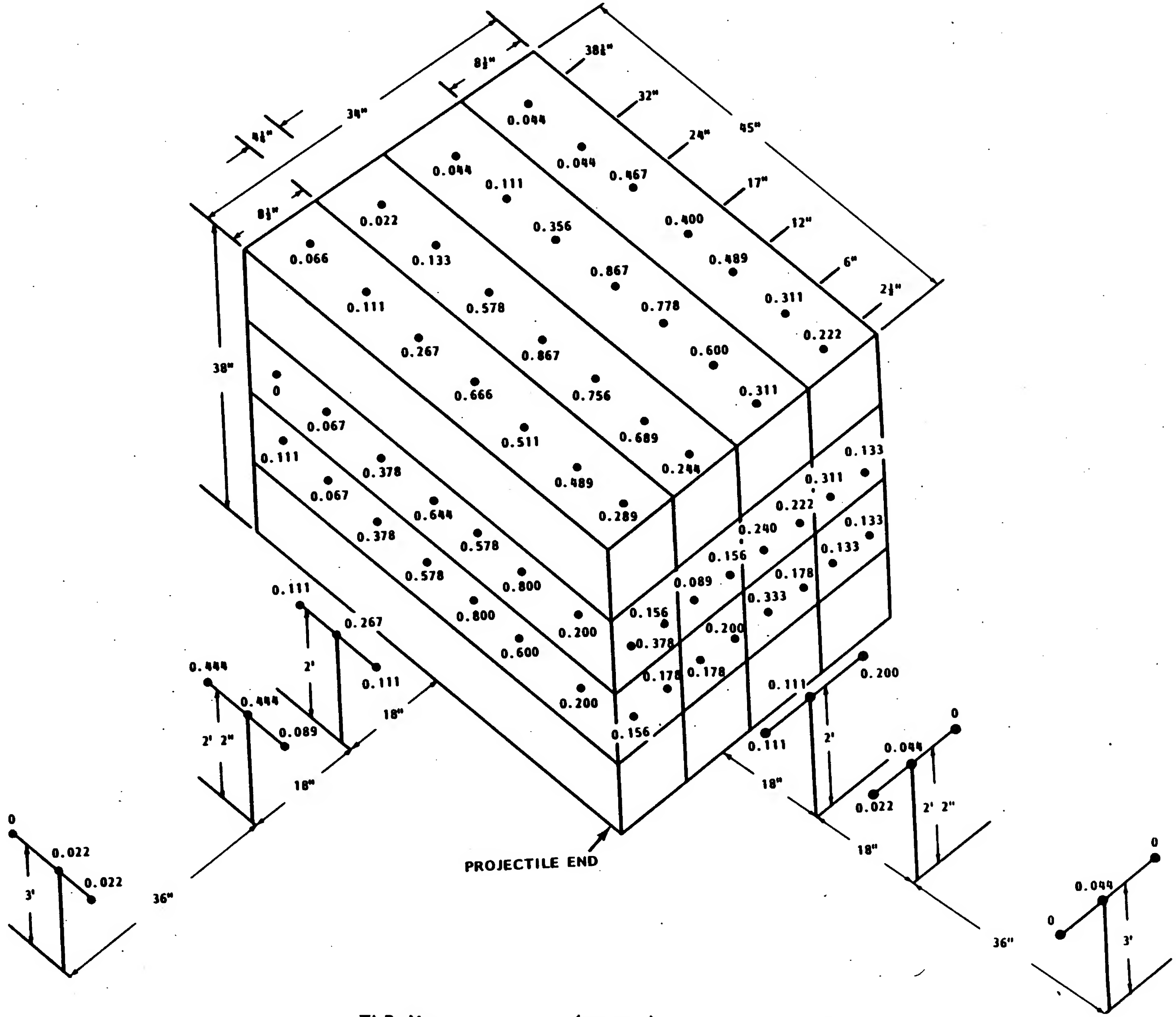
TLD Measurements (mR/hr) of Unpackaged Cartridge



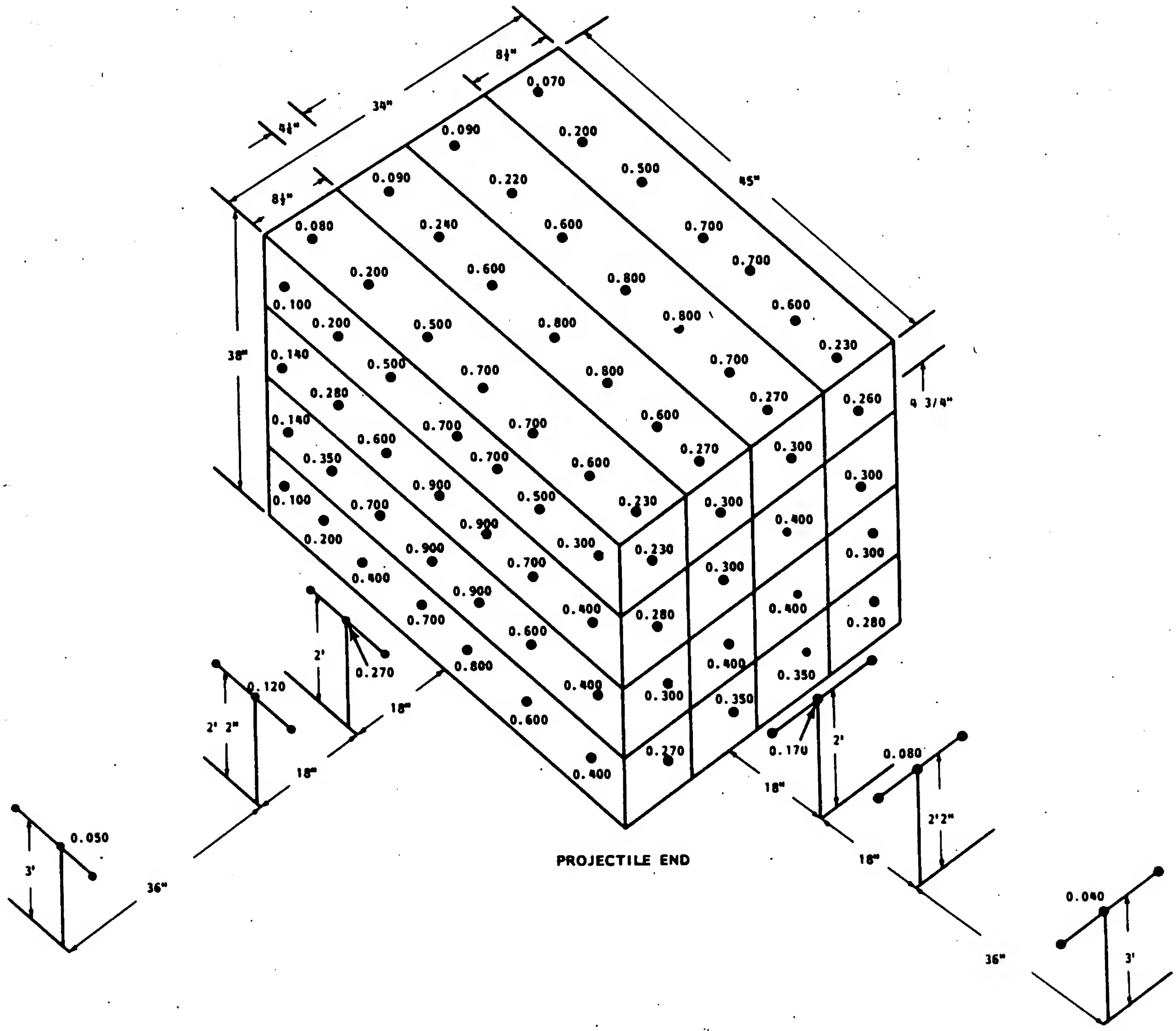
Micro-R Measurements (mR/hr) of Unpackaged Cartridge



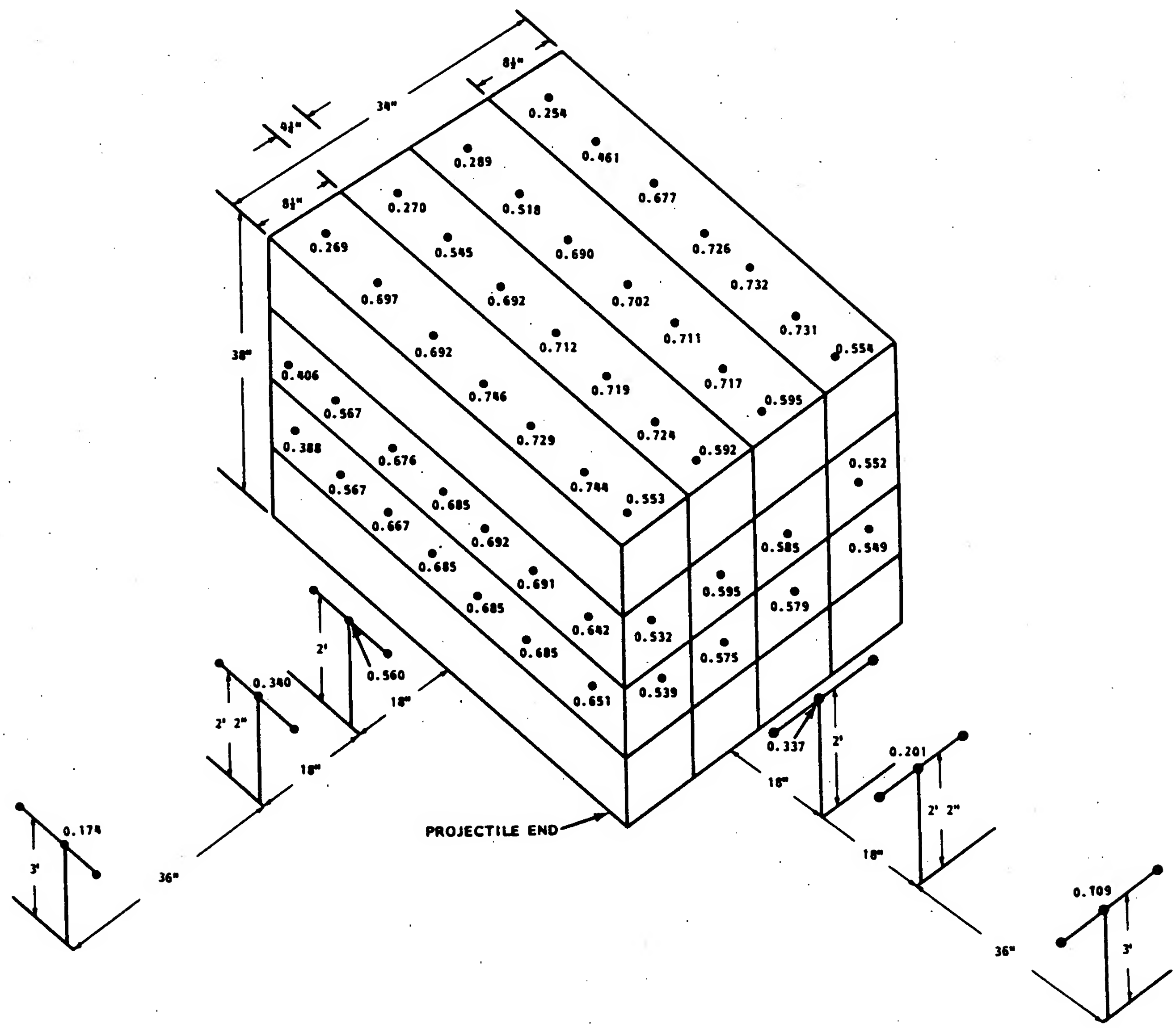
TASC-4 Measurements (mR/hr) of Unpackaged Cartridge



TLD Measurements (mR/hr) of 16-Round Pallet

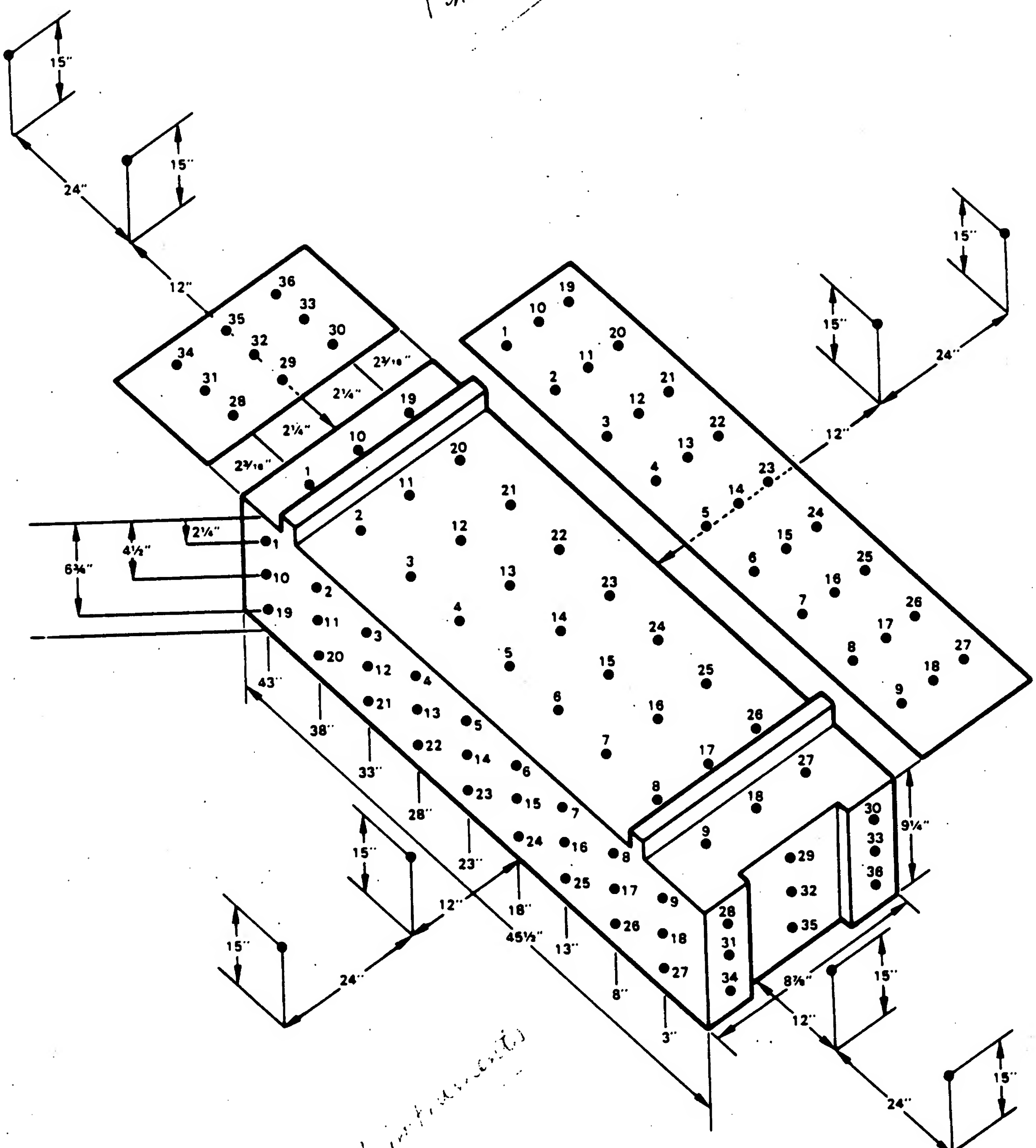


Micro-R Measurements (mR/hr) of 16-Round Pallet



TASC-4 Measurements (mR/hr) of 16-Round Pallet

max 0.4mr/hr



1 micro R instrument(s)

Portable Instrument Measurement Points on Shipping Container

FIRE IMPLICATIONS FROM UPLOADED VEHICLE (TACTICAL)

- TANK FIRE
  - UNSUSTAINED
  - SUSTAINED
- RESPONSE
- DOWNWIND CONSIDERATIONS
  - METEROLOGICAL CONDITIONS
- CONTROLS
- DOSE EVALUATIONS

MUNITIONS QUALITY CONTROL

SMALL CALIBER (10 - 30 MM)

LARGE CALIBER (75 - 155 MM)

DOA SUPPLIER SURVEYS

PREAWARD AND POST AWARD

HEALTH PHYSICS

FIRE PROTECTION

SUPPLIER HEALTH PHYSICS PROGRAM

LICENSE

RADIATION PROTECTION ORGANIZATION

PERSONNEL SELECTION AND TRAINING

EXPOSURE CONTROLS

RECORDS

SUPPLIER HEALTH PHYSICS PROGRAM

Radioactive Waste Management

ALARA Program

Facilities and Equipment

Emergency Preparedness

SUPPLIER FIRE PROTECTION

PRE FIRE PLANNING

FIRE PREVENTION

FIRE EXTINGUISHING

CONTAMINATION PROBLEMS ASSOCIATED WITH HARD IMPACT TESTING

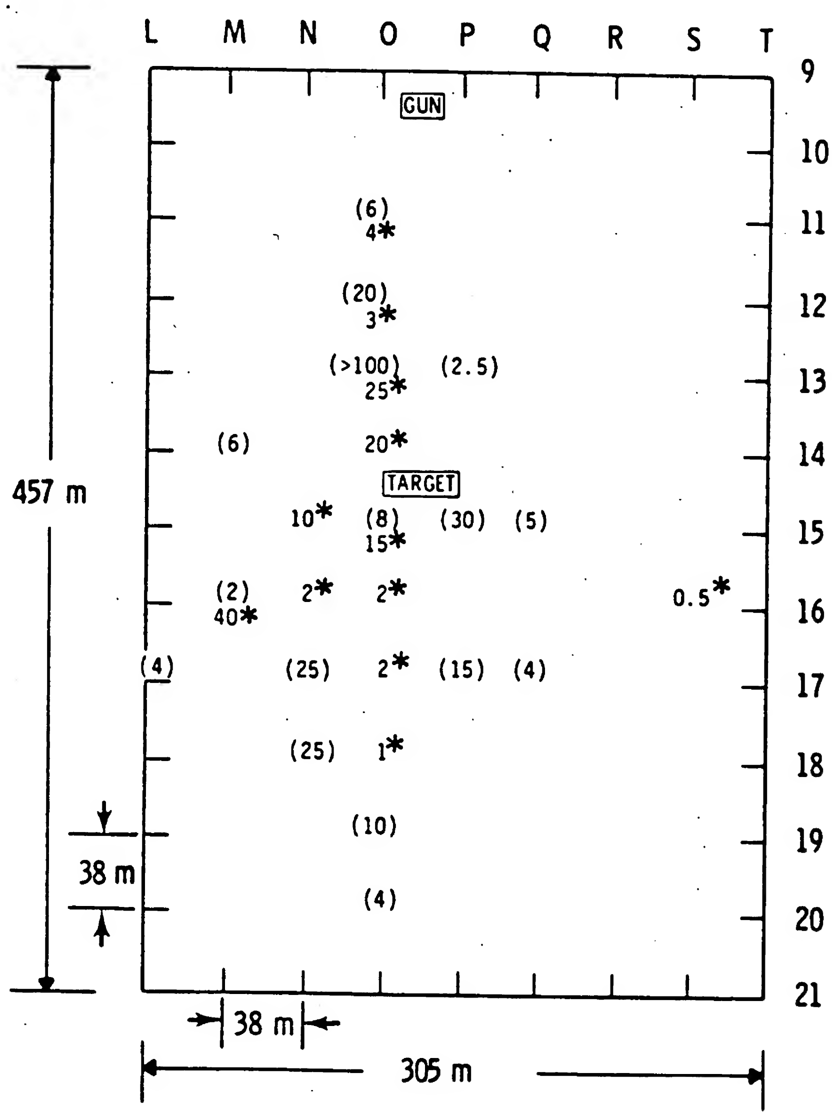
- Surface Contamination
- Airborne Contamination

SURFACE CONTAMINATION

- Particle Size
- Oxides
- Solubility
- Downwind Spread of Respirable Sized Particles

AIRBORNE CONTAMINATION

- Particle Size
- Oxides
- Aerosol
- Solubility
- Downwind Spread of Respirable Sized Particle
- Resuspension



( ) EARLY-SPRING TRIP

* LATE-SUMMER TRIP

FIGURE 5. Maximum Count Rates on Main Grid, Ford's Farm (1000 counts/min)

TABLE 6. Total Airborne Uranium Assuming 7.5 sec Sampling Interval at 50 cfm

Run	Exposure mg min/m^3	Concentration(a) mg/m^3	Cloud(b) m^3	Airborne(c) g	Approximate Mass % of a Penetrator(d)
1	150	1200	1500	1800	53
2	153	1220	1000	1220	36
3	215	1720	1700	2924	87
4	231	1850	1900	3515	104
				9,459	
				Ave = 2,365 or	70%

(a) Concentration $= \left[\frac{\text{mg x min}}{\text{m}^3}\right] \times \left[\frac{1}{0.125 \text{ min}}\right]$

(b) From Table 5.

(c) $g = \text{cloud, m}^3 \times \frac{\text{mg}}{\text{m}^3} \times \frac{\text{g}}{1000 \text{ mg}}$

(d) $\frac{c}{3365 \text{ g}} \times 100$

TABLE 9. Characteristics of Material Collected in a Target Area High-Volume Cascade Impactor During Runs 3 and 4

	Size Range μm	U:Fe wt ratio(a)	U Compounds Identified(b)
Run 3-I2	>7.0	5.4 ± 0.4	UO_2, U_3O_8
	3.3 to 7.0	9.6 ± 9.7	UO_2, U_3O_8
	2.0 to 3.3	8.7 ± 0.5	UO_2, U_3O_8
	1.1 to 2.0	7.8 ± 0.4	UO_2, U_3O_8
	<1.1	12.8 ± 0.4	U_3O_8
Run I2	>7.0	5.2 ± 0.6	UO_2, U_3O_8
	3.3 to 7.0	6.0 ± 0.7	UO_2, U_3O_8
	2.0 to 3.3	6.6 ± 0.5	UO_2, U_3O_8
	1.1 to 2.0	8.2 ± 0.2	UO_2, U_3O_8
	<1.1	12.8 ± 0.4	U_3O_8, UO_2

(a) Average of four measurements ± standard deviation.
(b) The compounds are listed in order of estimated abundance.

APPENDIX C

SAMPLE SIZE DISTRIBUTION DATA REDUCTIONS

TABLE C.1. High-Volume Cascade Impactor Example Size Distribution Run 1-I1

Stage	Aerodynamic Cut Off Dia., μm	Uranium on Sample, μg	% per Stage	Cumulative %
Probe		3.85×10^4	38.2	100.1
1	7.0	1.48×10^4		
2	3.3	1.11×10^4	8.0	61.8
3	2.0	0.596×10^4	4.3	53.9
4	1.1	0.281×10^4	2.0	49.6
Filter		6.64×10^4	47.6	47.6
		1.40×10^5		

TABLE 8. Relative Abundance of Uranium Oxides in Target Area Samples

Run Sample	UO_2 Weight Percent	U_3O_8 Weight Percent
1-T2	25	75
2-T1	28	72
3-T2	30	70
4-T3	27	73
5-T2	29	71

TABLE 10. Measured Solubilities of Airborne Depleted Uranium in Simulated Lung Fluid

Run Sample	Percent of Uranium into Solution in 7 Days	Approximate Dissolution Rate after 7 Days, (Percent Extracted per Day (a,c)
Run 3-I2(b)	47 + 10	0.1 + 0.7
Run 4-I2(b)	34 + 8.0	-0.5 + 0.5
Run 4-I3(b)	49 + 14	-0.5 + 1.0
Run 1-T2	16 + 3	0.2 + 0.2
Run 2-T1	13 + 3	-0.05 + 0.2
Run 3-T2	18 + 4	0.05 + 0.3
Run 4-T3	11 + 3	0.01 + 0.2
Run 5-T2	15 + 4	0.05 + 0.3

(a) A negative value indicates uranium lost or reabsorbed.
(b) Respirable fraction only.
(c) ± Estimated Standard Error

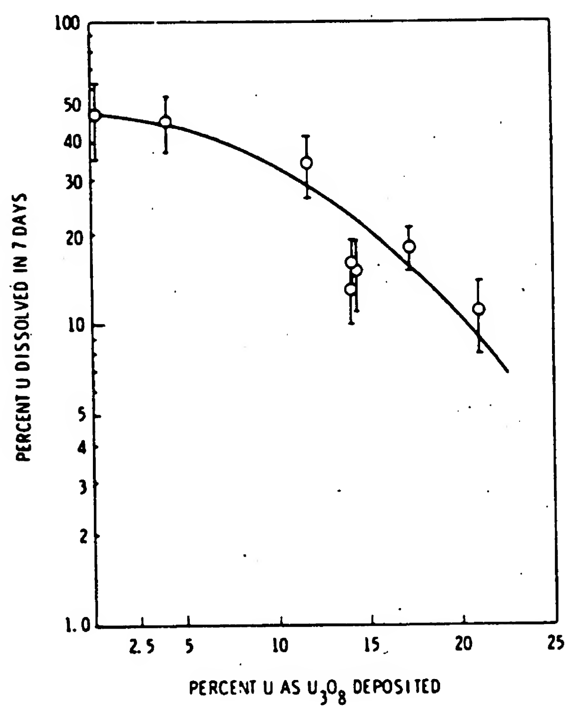


FIGURE 29. Percent Uranium Soluble in Seven Days Versus Mass of Uranium (as U_3O_8) in Sample

TABLE II

AIRBORNE RADIOACTIVITY ROUND 1 (M-48 TARGET)

PREFIRE BACKGROUND	5.89×10^{-13} µci/ml	below MPC
CREW COMPARTMENT (0-4 MIN. AFTER SHOT)	~~6.14×10^{-8}~~ µci/ml	4 orders of mag high
BUNKER 245' DOWNWIND	2.08×10^{-11} µci/ml	fact 4 high

ALL SAMPLES COLLECTED WITH STAPLEX HIGH VOLUME SAMPLER WITH WHATMAN 41 FILTER PAPER.

TABLE III

AIRBORNE RADIOACTIVITY ROUND 2 (M-48 TARGET)

CREW COMPARTMENT (0-10 MIN. AFTER SHOT)	~~5.2×10^{-9}~~ µci/ml	~3 orders mag high
BUNKER 245' DOWNWIND	7.66×10^{-13} µci/ml	below limits

NOTE: ROUND 2 DID NOT PENETRATE.

TABLE VIII

AIRBORNE RADIOACTIVITY ROUND 6

SAMPLE BACKGROUND OUTSIDE TANK	1.12×10^{-12} µci/ml
SAMPLE - CREW COMPARTMENT (WORKING INSIDE)	1.31×10^{-11} µci/ml

below MPC

above MPC factor 2.6 x [illegible]

NOTE: SAMPLES TAKEN 120 HOURS AFTER FIRING ROUND 6
SAMPLE INSIDE CREW COMPARTMENT WITH ASSESSMENT CREW WORKING.

TABLE IX

AIRBORNE RADIOACTIVITY ROUND 10

SAMPLE 1 (CREW COMPARTMENT PRIOR TO FIRING)	6.49×10^{-12} µci/ml
SAMPLE 2 (CREW COMPARTMENT AFTER NON DU ROUND)	2.90×10^{-11} µci/ml

still above MPC

above MPC up from Rd 6 indicates [illegible] from impact of Rd 10

ROUND 10 WAS A NONRADIOACTIVE 105MM APDSFS

TABLE VIII

AIRBORNE RADIOACTIVITY ROUND 6

SAMPLE BACKGROUND OUTSIDE TANK	1.12×10^{-12} μci/ml
SAMPLE - CREW COMPARTMENT (WORKING INSIDE)	1.31×10^{-11} μci/ml

below MPC

above MPC factor 2.6 x

NOTE: SAMPLES TAKEN 120 HOURS AFTER FIRING ROUND 6
SAMPLE INSIDE CREW COMPARTMENT WITH ASSESSMENT CREW WORKING.

TABLE IX

AIRBORNE RADIOACTIVITY ROUND 10

SAMPLE 1 (CREW COMPARTMENT PRIOR TO FIRING)	6.49×10^{-12} μci/ml
SAMPLE 2 (CREW COMPARTMENT AFTER NON DU ROUND)	2.90×10^{-11} μci/ml

still above MPC

above MPC up from Rd 6 indicates resuspension from impact of Rd 10

ROUND 10 WAS A NONRADIOACTIVE 105MM APDSFS

TABLE IV

PARTICLE SIZE DISTRIBUTION - ROUND 3

ANDERSON IMPACTOR		*DPM/STAGE		TOTAL	% OF TOTAL
STAGE NO.	PARTICLE SIZE	ALPHA	BETA	DPM*	ON EACH STAGE
1	9.2 μM>	20.9	869.0	889.9	32.0
2	5.5-9.2 μM	22.8	675.0	697.8	25.0
3	3.3-5.5 μM	4.8	269.9	274.7	9.9
4	2.0-3.3 μM	1.0	171.4	172.4	6.2
5	1.0-2.0 μM	37.0	204.4	241.4	8.7
6	-1.0 μM	7.0	492.0	499.0	18.0
TOTAL		93.5	2681.7	2775.2	

NOTE: SAMPLER IN DRIVER'S AREA

EST CONC = 1.77 x 10^{-7} μci/ml (INCLUDES RESUSPENDED MATERIAL)

* DPM = DISINTEGRATION PER MINUTE

Data Indicate high % respirable

TABLE X

REMOVABLE CONTAMINATION AFTER ROUND 1

AREA SAMPLED INSIDE CREW COMPARTMENT M-48	DPM ALPHA PER 100 cm^2	DPM BETA PER 100 cm^2	TOTAL µci PER 100 cm^2	Relationship to Permissible Level
IN PENETRATION	196	2,508	1.23×10^{-3}	high
AROUND PENETRATION	128	1,901	9.22×10^{-4}	high
BEHIND DRIVER'S SEAT	803	10,225	5.01×10^{-3}	high
BESIDE DRIVER'S SEAT	738	11,571	5.60×10^{-3}	high
TANK COMMANDER AREA	14	155	7.68×10^{-5}	low
GUNNER'S AREA	51	1,493	7.02×10^{-4}	high
PENETRATION REAR TURRET	39	492	2.41×10^{-4}	low
LOADER AREA	125	1,943	9.40×10^{-4}	high
TOP AMMO BOX DRIVER'S AREA	626	14,876	7.05×10^{-3}	high
DRIVER MANIKIN	608	10,052	4.85×10^{-3}	high
LOADER MANIKIN	320	4,425	2.16×10^{-3}	high

Indicates > permissable limits (Smearable) at 9 of 11 sample locations within tank

TABLE XI

REMOVABLE CONTAMINATION AFTER ROUND 2

AREA SAMPLED OUTSIDE SURFACE M-48	DPM ALPHA PER 100 cm^2	DPM BETA PER 100 cm^2	TOTAL µci PER 100 cm^2	
IN PENETRATION AREA	20	652	3.05×10^{-4}	low
GUN SHIELD	38	888	4.21×10^{-4}	slightly in
BACK OF GUN SHIELD	53	1680	7.88×10^{-4}	high
TOP OF TURRET	29	811	3.82×10^{-4}	slightly lo

NOTE: ROUND ~~DID NOT~~ PENETRATE

TABLE XII

REMOVABLE CONTAMINATION AT COMPLETION OF FIRINGS*

AREA SAMPLED INSIDE CREW COMPARTMENT M-48	DPM ALPHA PER 100 cm^2	DPM BETA PER 100 cm^2	TOTAL μci PER 100 cm^2	
RADIO	21.0	169.4	8.65×10^{-5}	low
TANK COMMANDER AREA	26.0	241.7	1.22×10^{-4}	low
TURRET ABOVE TANK COMMANDER	6.2	63.5	3.17×10^{-5}	low
FLOOR BELOW TANK COMMANDER	13.3	105.8	5.41×10^{-5}	low
FLOOR GUNNER'S AREA	17.2	125.1	6.47×10^{-5}	low
GUNNER'S CONTROL	53.7	343.7	1.81×10^{-4}	low
GUNNER'S AMMO CASE	17.2	292.6	1.41×10^{-4}	low
LOADER AMMO CASE	88.8	1431.1	6.91×10^{-4}	high
TURRET WALL LOADER AREA	34.4	388.7	1.92×10^{-4}	low
LOADER'S SEAT	3.0	79.1	3.73×10^{-5}	low
FLOOR LOADER'S AREA	24.5	383.7	1.86×10^{-4}	low
AMMO CASE DRIVER'S AREA	16.8	161.6	8.11×10^{-5}	low
WALL OF TANK NEAR RADIO	226.0	4686.7	2.23×10^{-3}	high
BREECH 90MM GUN	66.0	649.5	3.25×10^{-4}	low
TOP OF TURRET ABOVE GUN	15.4	159.6	7.95×10^{-5}	low
AMMO RACKS LEFT OF DRIVER	59.0	809.7	3.95×10^{-4}	low
AMMO RACKS RIGHT OF DRIVER	125.3	1415.7	7.00×10^{-4}	high
FLOOR DRIVER'S AREA	243.2	3911.6	1.89×10^{-3}	high
DRIVER'S SEAT	2.5	34.0	1.70×10^{-5}	low
DRIVER'S STEERING CONTROL	4.5	42.7	2.15×10^{-5}	low

*SURVEY PERFORMED 3 WEEKS AFTER FINAL FIRING.

above permissible limits at 4 of 20 sample locations after 3 weeks elapsed time

assumed to diminish because of rain & wind

TABLE XIII

REMOVABLE CONTAMINATION FOLLOWING DECONTAMINATION

AREA SAMPLED INSIDE CREW COMPARTMENT M-48	DPM ALPHA PER 100 cm^2	DPM BETA PER 100 cm^2	TOTAL μci PER 100 cm^2	
RADIO	48.8	643.6	3.1×10^{-4}	low
TANK COMMANDER AREA	3.0	4.9	3.6×10^{-6}	"
TURRET ABOVE TANK COMMANDER	6.7	15.5	1.0×10^{-5}	"
FLOOR BELOW TANK COMMANDER	4.8	98.5	4.7×10^{-5}	"
FLOOR-GUNNER'S AREA	85.6	1545.7	7.4×10^{-4}	high
GUNNER'S CONTROL	3.0	39.4	1.9×10^{-5}	low
GUNNER'S AMMO CASE	15.4	182.8	9.0×10^{-5}	"
LOADER'S AMMO CASE	48.7	475.4	2.4×10^{-4}	"
JRRET WALL LOADER'S AREA	15.4	124.6	6.4×10^{-5}	"
LOADER'S SEAT	19.4	170.0	8.6×10^{-5}	"
FLOOR-LOADER'S AREA	80.9	1121.3	5.5×10^{-4}	high
AMMO CASE DRIVER'S AREA	-	32.0	1.5×10^{-5}	low
WALL NEAR RADIO	20.7	173.1	9.8×10^{-5}	"
BREECH 90MM GUN	6.6	36.9	2.0×10^{-5}	"
TOP OF TURRET ABOVE GUN	0.2	134.4	6.1×10^{-5}	"
AMMO RACKS LEFT OF DRIVER	32.2	443.3	2.2×10^{-4}	"
AMMO RACKS RIGHT OF DRIVER	69.8	197.4	1.2×10^{-4}	"
FLOOR DRIVER'S AREA	NOT SAMPLED			
DRIVER'S SEAT	-	12.3	5.6×10^{-6}	low
DRIVER'S STEERING CONTROL	0.2	13.1	6.0×10^{-6}	low

. only 2 locations remained above permissable removable level
(probably ground in by cleaning crew)

ASSUMPTION 1: M-48 Tank attacked and successfully penetrated by 3.23 lb DU munition. Surviving crew personnel evacuate the tank in approximately 10 seconds. Maximum concentration of airborne material is 6.137×10^{-8} μci/ml. Breathing rate of crew is 20 liters/min. (Results from Table II)

$$
\begin{aligned}
\text{Exposure} &= \text{Volume of air breathed} \times \text{concentration} \\
&= \text{Exposure time (min)} \times \text{breathing rate (ml/min)} \\
&\quad \times \text{conc. } (\mu\text{ci/ml}) \\
&= (10/60 \text{ min})\ (2 \times 10^{4} \text{ ml/min} \times 6.137 \times 10^{-8}\ \mu\text{ci/ml} \\
&= 2.05 \times 10^{-4}\ \mu\text{ci}
\end{aligned}
$$

$$
\begin{aligned}
\text{Lung dose} &= 2.05 \times 10^{-4}\ \mu\text{ci} \times 22\ \text{REM}/\mu\text{ci} - 4.5 \times 10^{-3}\ \text{REM} \\
&= 4.5\ \text{MREM}
\end{aligned}
$$

$$
\begin{aligned}
\text{Bone dose} &= 2.05 \times 10^{-4}\ \mu\text{ci} \times 40\ \text{REM}/\mu\text{ci} - 8.2 \times 10^{-3}\ \text{REM} \\
&= 8.2\ \text{MREM}
\end{aligned}
$$

$$
\text{Weight of Uranium inhaled} = \frac{2.05 \times 10^{-4}\ \mu\text{ci}}{3.6 \times 10^{-4}\ \mu\text{ci/mg}} = 5.69 \text{ mg}
$$

NOTES:

1. Our calculation further assumes that all airborne particles collected are respirable (i.e., approx. 0.1 - 10 μm).
2. Assumes that all particles breathed are retained. Based on our impactor data, we believe that only about 50% of the airborne particles would be retained. Therefore, our result is an overestimate of the lung dose.

RADIATION SAFETY FOR TEST OPERATIONS

- BASELINE SURVEY
- CONTROL BOUNDRIES
- MONITORING OF APPLICABLE PARAMETERS DURING TESTING
- CONTROLLED RE-ENTRY
- FOLLOW-UP SURVEYS OF POST TEST CONDITIONS
- MONITORING CLEAN-UP OPERATIONS
- RELEASE SURVEYS

CONTAMINATED WASTE FROM TEST OPERATIONS

- Waste Identity
- Processing
- Disposal

AEROSOL SAMPLING

URANIUM MINES AND MILLS

URANIUM PROCESSING PLANTS

MUNITION ASSEMBLY PLANTS

MUNITION STORAGE FACILITIES

CLASSIFICATION OF AEROSOLS

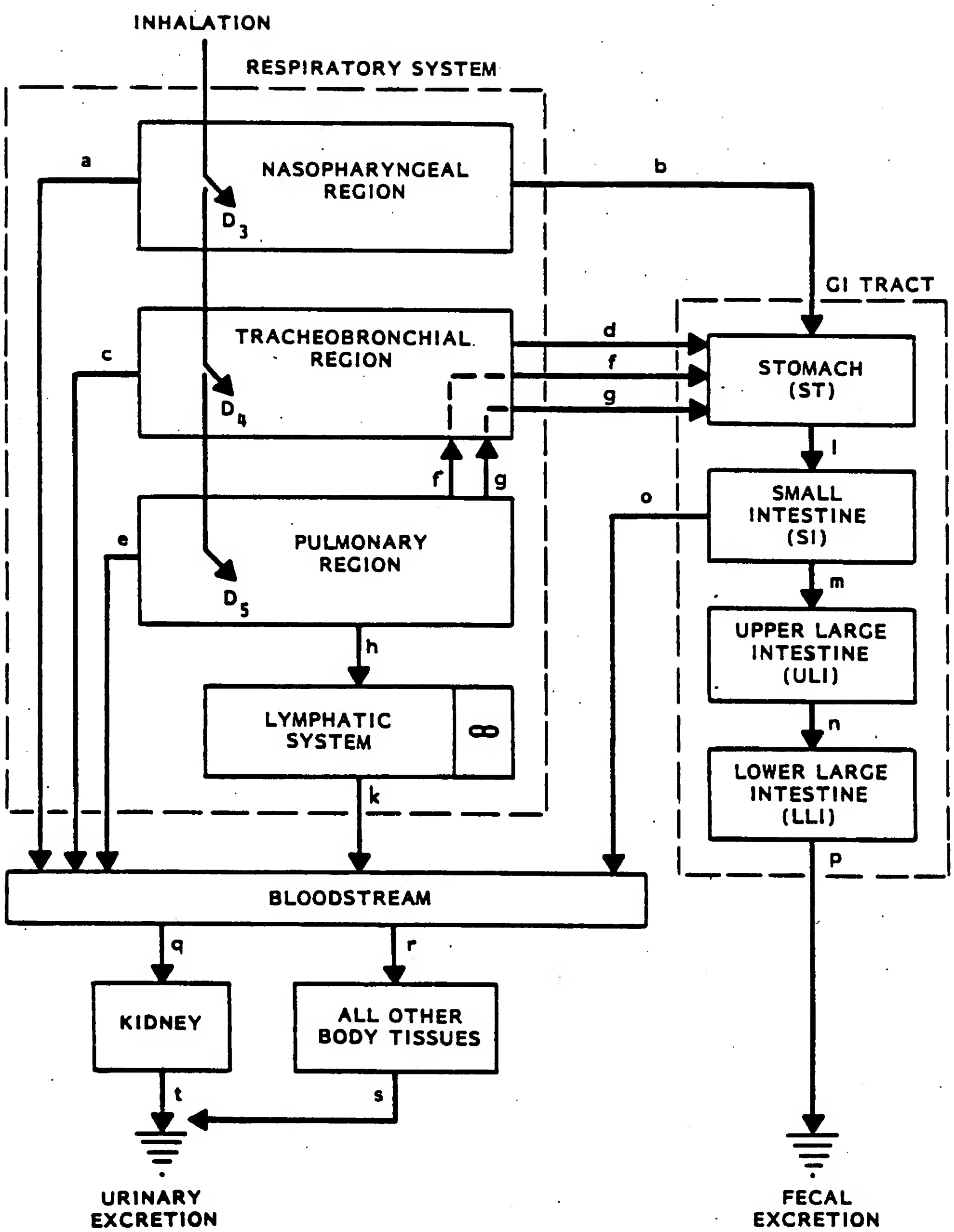
NAME	TYPE OF PARTICLE	DIAMETER SIZE RANGE (μm)	REMARKS
DUST	SOLID	>1	GENERATED BY MECHANICAL PROCESSES.
FUME	SOLID	<1	FORMED BY THE CONDENSATION OF VAPORS OF SOLID MATTER AFTER VOLATIZATION FROM THE MOLTEN STATE.
SMOKE	SOLID	0.001 TO 1	INCOMPLETE COMBUSTION PRODUCTS OF CARBONACEOUS MATERIAL.
MIST	LIQUID	40-500	FORMED BY CONDENSATION OF VAPORIZED LIQUIDS.
FOG	LIQUID	<40	FORMED BY CONDENSATION OF VAPORIZED LIQUIDS.
SPRAY	LIQUID	>10	MECHANICAL DISPERSOID OF LIQUID ORIGIN.

AEROSOL SAMPLING

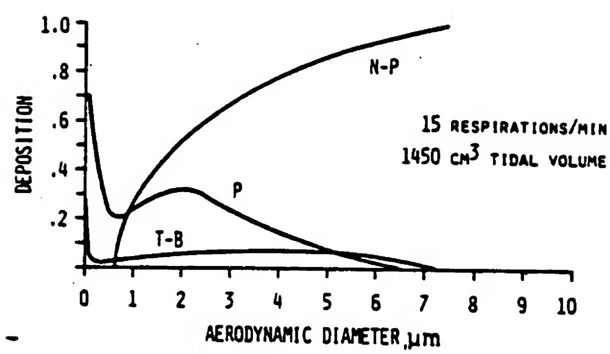
<u>RESPIRABLE</u> - THAT PORTION OF THE INHALED DUST WHICH IS DEPOSITED IN THE NON-CILIATED PORTION OF THE LUNGS.

AEROSOL SAMPLING

Aerodynamic Diameter (μm)	Percent Respirable
10	0
5	25
3.5	50
2.5	75
2.0	100

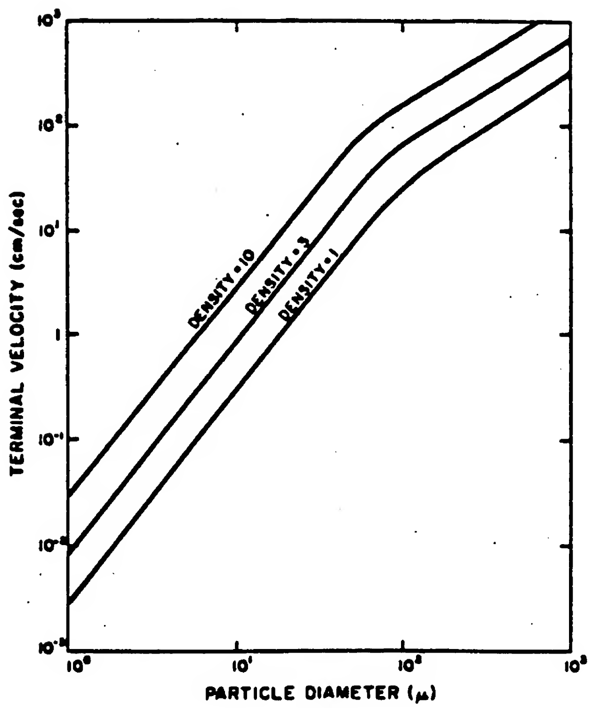

INHALATION
RESPIRATORY SYSTEM
NASOPHARYNGEAL REGION
D_3
TRACHEOBRONCHIAL REGION
D_4
PULMONARY REGION
D_5
LYMPHATIC SYSTEM
GI TRACT
STOMACH (ST)
SMALL INTESTINE (SI)
UPPER LARGE INTESTINE (ULI)
LOWER LARGE INTESTINE (LLI)
BLOODSTREAM
KIDNEY
ALL OTHER BODY TISSUES
URINARY EXCRETION
FECAL EXCRETION
a
b
c
d
e
f
g
h
k
l
m
n
o
p
q
r
s
t

AEROSOL SAMPLING



Calculated deposition of particles in the nasopharyngeal (N–P), tracheobronchial (T–B), and pulmonary (P) compartments, relative to number inhaled.

AEROSOL SAMPLING



Terminal velocities for spheres of various sizes and densities in air at S.T.P.

AEROSOL SAMPLING

SELECTION OF SAMPLING LOCATIONS

AREA SAMPLING
PERSONNEL SAMPLING

AEROSOL SAMPLING

Selection of Sampling Equipment

Air Samplers

Filter Media

AEROSOL SAMPLING

SAMPLING FREQUENCY

RECORDS REQUIREMENTS

ENVIRONMENTAL MONITORING

RELATIONSHIP TO RADIATION SAFETY PROGRAM

ELEMENTS OF THE ENVIRONMENTAL MONITORING PROGRAM

RECORDS REQUIREMENTS

CONSTANTS AND FORMULA

$1 \text{ Ci} = 3.7 \times 10^{10}$ dps $= 2.22 \times 10^{12}$ dpm

3.6×10^{-7} Ci/g Dci

453.59 grams/pound

5.26×10^{5} min/year

$N = 6.023 \times 10^{23}$ atoms/mole

28,320 cc/ft³

$t_{1/2}\ U_{235} = 7.1 \times 10^{8}$ years

$t_{1/2}\ U_{234} = 2.47 \times 10^{5}$ years

$t_{1/2}\ U_{238} = 4.51 \times 10^{9}$ years

$t_{1/2}\ Th_{234} = 24.1$ d

$t_{1/2}\ Th_{230} = 8.0 \times 10^{4}$ y

$t_{1/2}\ Rn_{222} = 3.82$ days

$Ra_{226} = 1602$ y

$\lambda = 0.693/t_{1/2}$

$$\text{Specific Activity} = \frac{N \times 1.873 \times 10^{-11}}{t_{1/2}}$$

N = number of atoms/gram

$t_{1/2}$ = half life in seconds

June 1974

U.S. ATOMIC ENERGY COMMISSION

REGULATORY GUIDE

DIRECTORATE OF REGULATORY STANDARDS

REGULATORY GUIDE 8.11

APPLICATIONS OF BIOASSAY FOR URANIUM

A. INTRODUCTION

Section 20.108, "Orders Requiring Furnishing of Bioassay Services," of 10 CFR Part 20, "Standards for Protection Against Radiation," states that the Atomic Energy Commission may incorporate in any license provisions requiring bioassay measurements as necessary or desirable to aid in determining the extent of an individual's exposure to concentrations of radioactive material. As used by the Commission, the term bioassay includes *in vivo* measurements as well as measurements of radioactive material in excreta. This guide provides criteria acceptable to the Regulatory staff for the development and implementation of a bioassay program for mixtures of the naturally occurring isotopes of uranium – U-234, U-235, and U-238. The guide is programmatic in nature and does not deal with laboratory techniques and procedures. Uranium may enter the body through inhalation or ingestion, by absorption through normal skin, and through lesions in the skin. However, inhalation is by far the most prevalent mode of entry for occupational exposure. The bioassay program described in this guide is applicable to the inhalation of uranium and its compounds, but does not include the more highly transportable compounds UF_6 and UO_2F_2.

Significant features of the bioassay program developed in this guide are listed below:

1. A bioassay program is necessary if air sampling is necessary for purposes of personnel protection. The extent of the bioassay program is determined by the magnitude of air sample results.

2. A work area qualifies for the "minimum bioassay program" so long as the quarterly average of air sample results is $\leq$10% of the Derived Air Concentration (DAC) and the maximum used to obtain the average is $\leq$25% of DAC. It must be demonstrated that air sample results used for this purpose are representative of personnel exposure.

3. Under the minimum program, bioassays are performed semiannually or annually for all workers to monitor the accumulation of uranium in the lung and bone. More frequent bioassays are performed for a sample of the most highly exposed workers as a check on the air sampling program; these bioassays are performed at sufficient frequency to assure that a significant single intake of uranium will be identified before biological elimination of the uranium renders the intake undetectable.

4. If a work area does not qualify for the minimum program, bioassays in addition to the minimum program are performed at increasingly higher frequencies, depending on the magnitude of air sample results.

5. A model is used which correlates bioassay measurement results with radiation dose or with uptake of uranium in the blood (chemical toxicity).

6. Actions are specified, depending upon the dose or uptake indicated by bioassay results. These actions are corrective in nature and are intended to ensure adequate worker protection.

7. Guidance is referenced for the difficult task of determining, from individual data rather than models, the quantity of uranium in body organs, the rate of elimination, and the dose commitment.

This bioassay program encourages improvement in the confinement of uranium and in air sampling techniques by specifying bioassays only to the extent that confinement and air sampling can not be entirely relied upon for personnel protection.

(3) Personnel, space, equipment, and support resources should be provided as necessary to conduct the program.

(4) An effective method of periodic internal audit of the protection program should be maintained.

(5) Before assigning employees to work in an area where exposure to uranium contamination may occur, action should be taken to ensure that facility and equipment safeguards necessary for adequate radiation protection are present and operable, that the employees are properly trained, that adequate procedures are prepared and approved, that an adequate surface and air contamination survey capability exists, that a bioassay program at least equivalent to the program described in this guide will be maintained, and that survey and bioassay records will be kept.

b. Bioassay Program

In the development of a bioassay program the following guides should be implemented:

(1) Necessity

The determination of the need for bioassay measurements should be based on air contamination monitoring results in accordance with criteria contained in this guide.

(2) Preparatory Evaluation

Before assigning an employee to work in an area where substantial exposure to uranium contaminants may occur, his condition with respect to radioactive material of similar chemical behavior previously deposited and retained in his body should be determined and the necessity for work restrictions evaluated.

(3) Exposure Control

The bioassay program should include, as appropriate, capabilities for excreta analyses and *in vivo* measurements, made separately or in combination at a sufficiently high frequency to assure that engineered confinement and air and surface contamination surveys are adequate for employee protection. The program should include all potentially exposed employees.

(4) Diagnostic Evaluation

The bioassay program should include capabilities for excreta analyses and *in vivo* measurements as necessary to estimate the quantity of uranium deposited in the body and/or in affected organs and the rate of elimination from the body and/or affected organs.

3. Operational Guidance

a. Criteria for Determining the Need for a Bioassay Program

Where air sampling is required for purposes of occupational exposure control, bioassay measurements are also needed (Table 1). The bioassay frequency should be determined by air sample results as averaged over 1 quarter.

Testing should be performed to determine whether air sampling is representative of personnel exposures. Air sample results which have been verified as representative may be used to determine the quarterly average.

If the 1-quarter average does not exceed 10% of the appropriate Derived Air Concentration (DAC) from Appendix B to 10 CFR Part 20 and if the maximum result used in the calculation of the average does not exceed 25% of DAC, only a minimum bioassay program is necessary (Table 2). If the 1-quarter average exceeds 10% DAC, or if the maximum result exceeds 25% of the DAC, additional bioassays are necessary (Table 3), except as noted below. Frequency criteria for both cases are discussed in Section C.3.c. The approach is illustrated in Figure 1.

The additional bioassays are not performed for a specific individual if the licensee can demonstrate that the air sampling system used to protect the individual is adequate to detect any significant intake and that procedures exist for diagnostic bioassays following detection of an apparently large intake.

The necessity for bioassay measurements may also arise following an incident such as a fire, spill, equipment malfunction, or other departure from normal operations which caused, or could have caused, abnormally high concentrations of uranium in air. Criteria for determining this necessity are shown in Figure 2. (The term "Early Information" refers to an instrumented air sampler with an alarm device.) Reliance cannot be placed on nasal swab results from mouth breathers; bioassays should be performed.

Special bioassay measurements should be performed to evaluate the effectiveness of respiratory protection devices. If an individual wearing a respiratory protection device is subjected to a concentration of transportable uranium in air within a period of 1 week such that his exposure with no respiratory protection device would have exceeded 40 x DAC μCi-hr/cc, urinalysis should be performed to determine the resulting actual uranium uptake. If an individual wearing a

TABLE 2
BIOASSAY FREQUENCY FOR EXPOSURE CONTROL

Program	Objective	Dust Classification	Measurement Technique[a]	Frequency
Minimum[b] Adequate if $QA < 1/10$ DAC and $M < 1/4$ DAC	Check on air sampling program and on confinement procedures and equipment.	(D) (W) (Y)	u iv iv	Use Figures 3 and 4 Use Figure 6 Semiannual
	Monitor lung burden buildup.	(W) (Y)	iv iv	Annual[c] Semiannual[c]
	Monitor bone burden buildup.	(D) (W) (Y) (Y)	u u u u	Semiannual Semiannual Class (D) or Class (W) Not Present, Annual[d] Class (D) or Class (W) Present, Semiannual[d]
Additional Acceptable if $QA > 1/10$ DAC and/or $M > 1/4$ DAC	Detect unsuspected intake.	(D) (W) (Y)	u iv, f, or u iv, f, or u	Use Table 3[e] Use Table 3[e] Use Table 3[e]

[a]iv, *in vivo*; u, urinalysis; f, fecal analysis.

[b]QA, quarterly average of air sample results; M, maximum result used to determine QA.

[c]These frequencies are applicable if no individuals are near work restriction limits. Quarterly or even monthly iv may become necessary as workers approach these limits.

[d]Special urinalysis should be performed each time exposure to new Class (Y) material begins to determine if more transportable component is present.

[e]These measurements are additional to those listed above for the minimum program. If it is demonstrated that air sampling provided for a specific individual is adequate to detect any significant intake and that procedures exist for diagnostic bioassays following detection of an apparently large intake, these additional measurements need not be performed.

frequent bioassays should be performed even though there is no such indication from air samples. In this case, however, improvements in the air sampling program are required rather than more frequent bioassays. The appropriate frequency can be determined from air sample data if the air sampling program is adequately representative of inhalation exposures.

If workers are exposed to a mixture of uranium compounds, the DAC for the mixture, DAC_m, should be calculated as

$$DAC_m = \left[\sum_{i=1}^{n} \frac{f_i}{DAC_i} \right]^{-1}$$

where DAC_i is the DAC for the ith compound and f_i is a fraction representing the contribution of the ith compound. The calculation of f_i depends on the exposure mode. If the material is a mixture, f_i is the activity fraction. For exposure in more than one area, f_i is the time fraction spent in the ith area. As an alternative DAC_m may be taken as the lowest DAC_i. As to the quarterly average for air samples, if the material is a mixture and exposure occurs in only one area, the quarterly average calculation, applicable to all workers in the area, should be performed as for non-mixtures, i.e., from samples characterizing conditions in the area. If exposures occur in several areas, the quarterly average for the mixture may be a time-weighted average for the individual, using quarterly average air samples that characterize full-time conditions in each area, i.e.,

$$QA_m = \sum_{i=1}^{n} f_i \ QA_i$$

where QA_i is the quarterly average for the ith area and f_i is the time fraction of the quarter that the individual worked in the ith area. As an alternative, QA_m may be taken as the highest QA_i.

Figure 5 indicates that a urinalysis measurement sensitivity of about 0.7 pCi/l is required to detect the equivalent of 1 MPD_c following a single exposure to Class (Y) materials with neither Class (D) nor Class (W) "tracer" dusts present. To obtain this sensitivity, a chemical concentration procedure is necessary. Fecal analysis is recommended as an alternative, using the frequency schedule given for urinalysis.

If work restrictions that have been imposed do not involve total exclusion from restricted areas, it is necessary to ensure that bioassay measurements made for the purpose of removing work restrictions are performed at least as frequently as would be required for purposes of exposure control.

A monthly *in vivo* frequency may be reduced to quarterly if weekly fecal analyses are made, with an *in vivo* measurement at the end of the quarter. An *in vivo* measurement should be performed as soon as practicable if the excretion rate exceeds 7 pCi/day Class (Y) or 700 pCi/day Class (W). For lower results the following procedure should be followed. Results from the first 4 weekly specimens should be plotted (semilog) against time, and a best fitting curve should be extrapolated to t = 0, thus obtaining an estimate of the initial excretion rate, $(dP'/dt)_o$, and the individual's half-life, T. The dose commitment, D_c, should be estimated using these values with the following equation:

$$D_c = 8.4\,T^2 \left[\frac{dP'}{dt}\right]_o$$

where T is in days and $(dP'/dt)_o$ is in µCi/day. The actions indicated in Table 4 should then be taken. This procedure should be repeated at the end of 8 weeks when results from 8 specimens are available. At the end of the quarter D_c should be evaluated using results from all 12 specimens. If the indicated D_c is $\leqslant$ 3 rems, the *in vivo* measurement may be considered unnecessary. If the D_c indicated by the fecal data exceeds 3 rems, the *in vivo* measurement should be performed.

A quarterly *in vivo* frequency may be reduced to semiannual if monthly fecal analyses are made, with an *in vivo* measurement at the end of 6 months. If any result exceeds 7 pCi/day Class (Y) or 460 pCi/day Class (W), an *in vivo* measurement should be performed as soon as practicable. For lower results the following procedure should be followed. Results from the first 3 specimens should be plotted (semilog) against time, and a best-fitting straight line should be extrapolated to t = 0. Values for $(dP'/dt)_o$ and T for the individual should be obtained and used in the above equation to estimate D_c. The actions indicated in Table 4 should then be taken. At the end of the fourth and fifth month, D_c should again be evaluated using results from all specimens. At the end of the 6-month period, the *in vivo* measurement should be performed.

Fecal specimens used for this purpose should be obtained after 2 or more days of no exposure. In the extrapolation of excretion rate data to t = 0, it is necessary to ignore data points obtained for less than 2 days after exposure.

d. Participation

All personnel whose regular job assignments involve work in an area where bioassay measurements are required should participate in the bioassay program. However, as long as air sample results qualify the area and group of workers for the minimum bioassay program, special consideration may be given in the case

TABLE 4
ACTION DUE TO BIOASSAY MEASUREMENT RESULTS, RADIATION DOSE

Result $\leq$ 1/5 MPD_c[a]

Contamination confinement and air sampling capabilities are confirmed. No action required.

1/5 < Result $\leq$ 1/2 MPD_c

Contamination confinement and/or air sampling capabilities are marginal. If a result in this range was expected because of past experience or a known incident, any corrective action to be taken presumably has been or is being accomplished; no action is required by the bioassay result. If the result was unexpected:

(1) Confirm result (air sample data review, comparison with other bioassay data, additional bioassay measurements).

(2) Identify probable cause and, if necessary, correct or initiate additional control measures.

(3) Determine whether others could have been exposed and perform bioassay measurements for them.

(4) If exposure (indicated by excreta analysis) could have been to Class (W) or Class (Y) dust, consider the performance of diagnostic *in vivo* measurements.

1/2 < Result $\leq$ 1 MPD_c

Contamination confinement and/or air sampling capabilities are unreliable unless a result in this range was expected because of a known unusual cause; in such cases, corrective action in the work area presumably has been or is being taken, and action due to the bioassay result includes action (7) only. Conditions under which a result in this range would be routinely expected are undesirable. If the result was due to such conditions or was actually unexpected, take actions (1) through (4) and:

(5) If exposure (indicated by excreta analysis) could have been to Class (W) or Class (Y) dust, assure that diagnostic *in vivo* measurements are performed.

(6) Review the air sampling program; determine why air samples were not representative and make necessary corrections.

(7) Perform additional bioassay measurements as necessary to make a preliminary estimate of the critical organ burden; consider work limitations to ensure that the MPD_c is not exceeded.

(8) If exposure could have been to Class (Y) dust, bring expert opinion to bear on cause of exposure, and continue operations only if it is virtually certain that the limit of 1 MPD_c will not be exceeded by any worker.

Result > 1 MPD_c

Contamination confinement and/or air sampling capabilities are not acceptable, unless a result of this magnitude was expected because of a known unusual cause; in such cases, corrective action in the work area presumably has been or is being taken, and action due to the bioassay result includes actions (10) and (11) only. Prevalent conditions under which a result in this range would be expected are not acceptable. If the result was due to such conditions or was actually unexpected, take actions (1) through (7) and:

(9) Take action (8), regardless of dust classification.

(10) Establish work restrictions as necessary for affected employees.

(11) Perform individual case studies (bioassays) for affected employees.

[a]The annual MPD_c is a 50-yr integrated dose of 15 rems to the lung or 30 rems to the bone.

by *in vivo* techniques is shown in Figure 15 for Class (W) materials and in Figure 16 for Class (Y) materials. Recommended actions, from Table 4, are indicated. These figures are applicable to uranium of 20 w/o U-235; scaling factors are provided in Figure 17 for other enrichments.

(5) Exposure to Mixtures

If a positive urinalysis specimen is obtained following exposure to a mixture that included significant quantities of Class (Y) materials, actions (1) through (11) in Table 4 should be taken.

If the exposure was to a mixture of Class (W) dust and Class (D) dust with chemical toxicity limiting, the urinary uranium mass concentration should be determined and the curves in Figure 9 used to determine the required actions from Table 5; the activity concentration should also be determined, using Figure 12 with Table 4.

If exposure was to a mixture of Class (W) dust and Class (D) dust with bone dose limiting, it is necessary to estimate the fraction of the dust inhaled that was Class (W), f_w, and the fraction that was Class (D), f_d. It is also necessary to determine the urinary excretion factors, E_w and E_d, that would be applicable at the time the specimen was obtained; Figure 18 may be used for this purpose. If R represents the bioassay result in pCi/day, R_d the Class (D) component and R_w the Class (W) component, such that $R = R_d + R_w$, then

$$R_d = f_d E_d R/(f_d E_d + f_w E_w)$$

$$R_w = f_w E_w R/(f_d E_d + f_w E_w)$$

These results should be converted to concentration using the factor 1.4 l/day. Then the curves in Figure 8 or Figure 12 should be used to determine the required actions from Table 4.

If positive *in vivo* results are obtained following exposure to a mixture of Class (W) and Class (Y) materials, Figure 16 should be used to determine the required actions from Table 4.

(6) Lung Burden Correlations, Continuous Intake

In some working areas airborne uranium is routinely present and is responsible for the chronic appearance of uranium in urine. Continuous intakes of this nature may also be responsible for chronically positive *in vivo* measurement results. Under these conditions positive bioassay results are expected, and the monitoring tasks are to measure the lung burden buildup and to identify single intake peaks above this expected level. Thus it is evident that for purposes of exposure control the chronic levels due to continuous intake do not alter the approach outlined for the detection of single intakes.

The correlation between *in vivo* measurements of U-235 and lung burden is shown in Figure 19. *In vivo* measurements are considered to be much more reliable than urinalysis for Class (W) and Class (Y) materials. However, urinalysis may be used to indicate that *in vivo* measurements are promptly needed. The average value from several urinalysis results ($\bar{R}$) can be used with Figure 20 to estimate the number of maximum permissible lung burdens (MPLB = 0.016 μCi). Arrangements for *in vivo* measurements should be undertaken when $\phi\bar{R}$ is found to exceed 0.5. If $\phi\bar{R} > 1$, additional exposure should be avoided until *in vivo* results are available.

(7) Referral to a Physician

When confirmed bioassay measurement results indicate that the Maximum Permissible Annual Dose (MPAD) to the lung or bone has been or will be exceeded by a factor of 2, the affected individual should be so informed, and referral to a physician knowledgeable in the biological effects of radiation and conversant in the nature and purpose of regulatory dose limits should be considered.

When confirmed bioassay results indicate that an exposure to uranium has resulted in an uptake by the blood of more than 2.7 mg within 7 consecutive days or less, the affected individual should be informed of his exposure and referred to a physician knowledgeable in the chemical effects of internally administered uranium.

(8) Work Restrictions

AEC regulations establish an upper limit on exposures during a specified period of time; it follows that work restrictions may be necessary to prevent exposures from exceeding this limit. Such restrictions may also be necessary to prevent the deposition of uranium in the body in such quantity that:

(i) the mass of uranium entering the blood will exceed 2.7 mg in 7 consecutive days;
(ii) the activity present in the lung will produce an annual dose-equivalent to the pulmonary region exceeding 15 rems;
(iii) the activity present in the bone will produce an annual dose-equivalent to the bone exceeding 30 rems.

For personnel who have a body burden of uranium that is producing an annual dose-equivalent greater than 15 rems to the pulmonary region of the lung or 30 rems to the bone or both, work restrictions

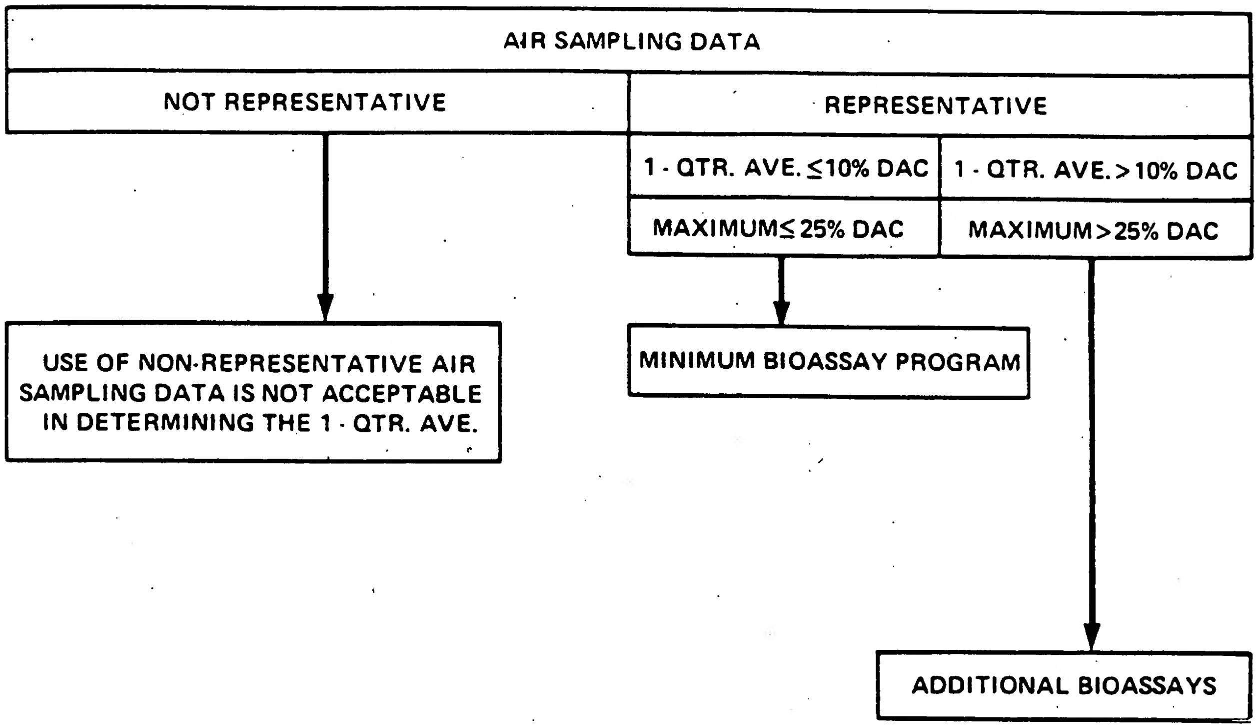


Figure 1 Criteria for Initiating Additional Bioassays, Routine Conditions

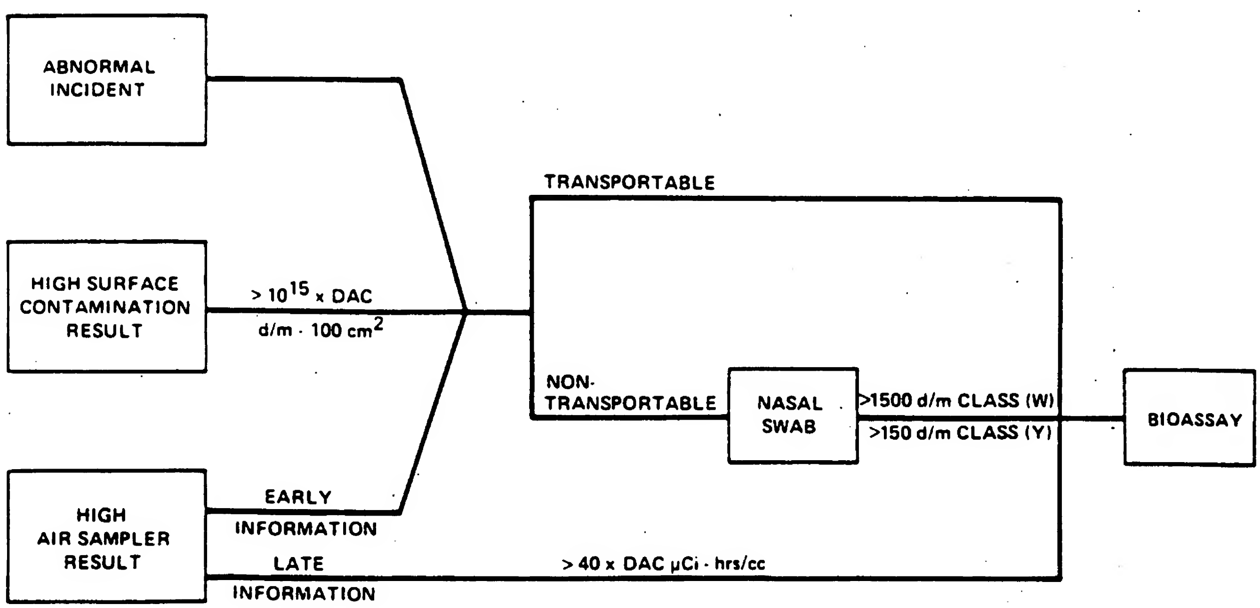


Figure 2 Criteria for Diagnostic Bioassays Durings Special Investigations

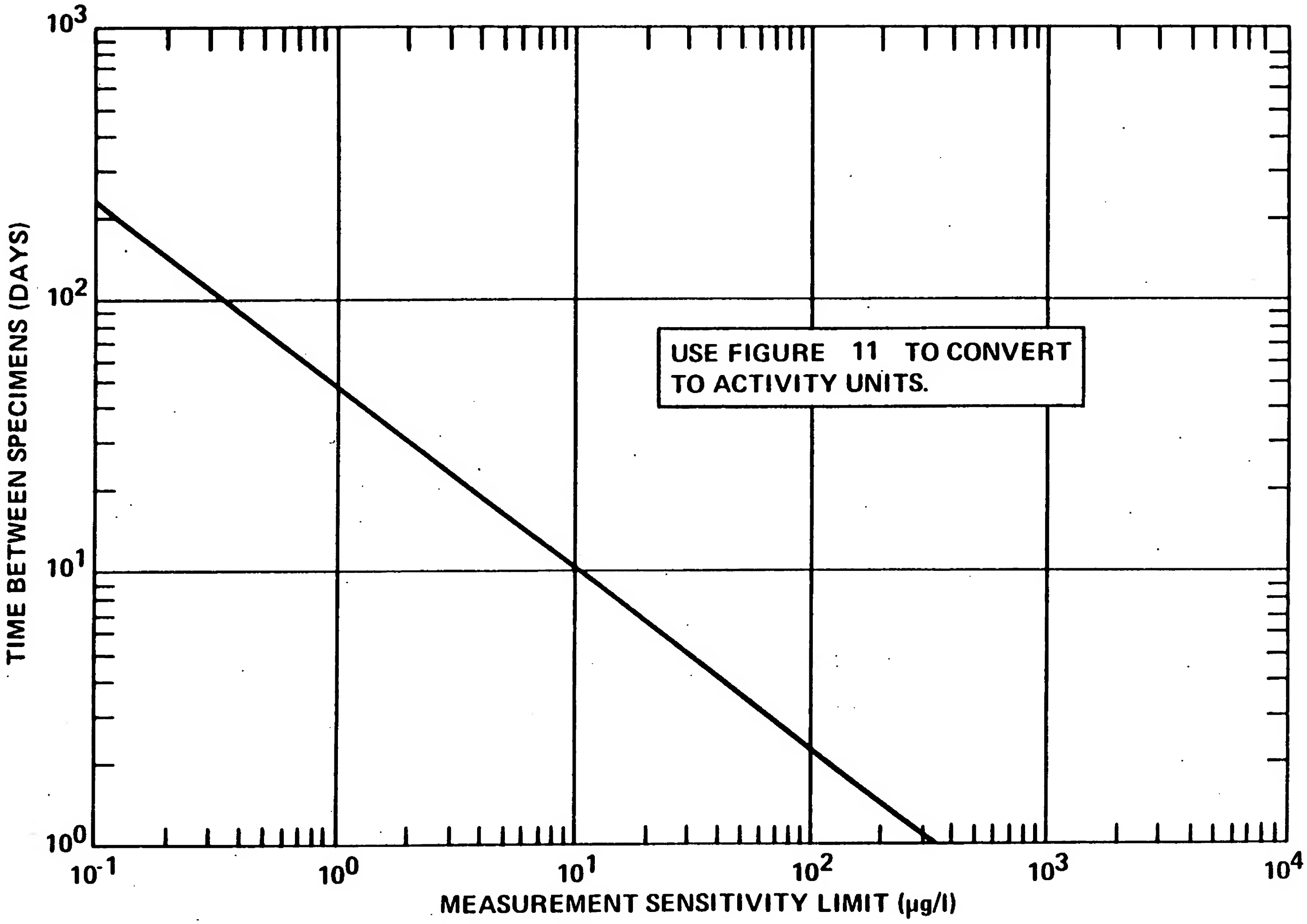


Figure 4 Maximum Time Between Specimens to Detect Uptake of 2.7 mg Class (D) Uranium, w/o U-235 $\leq$ 80

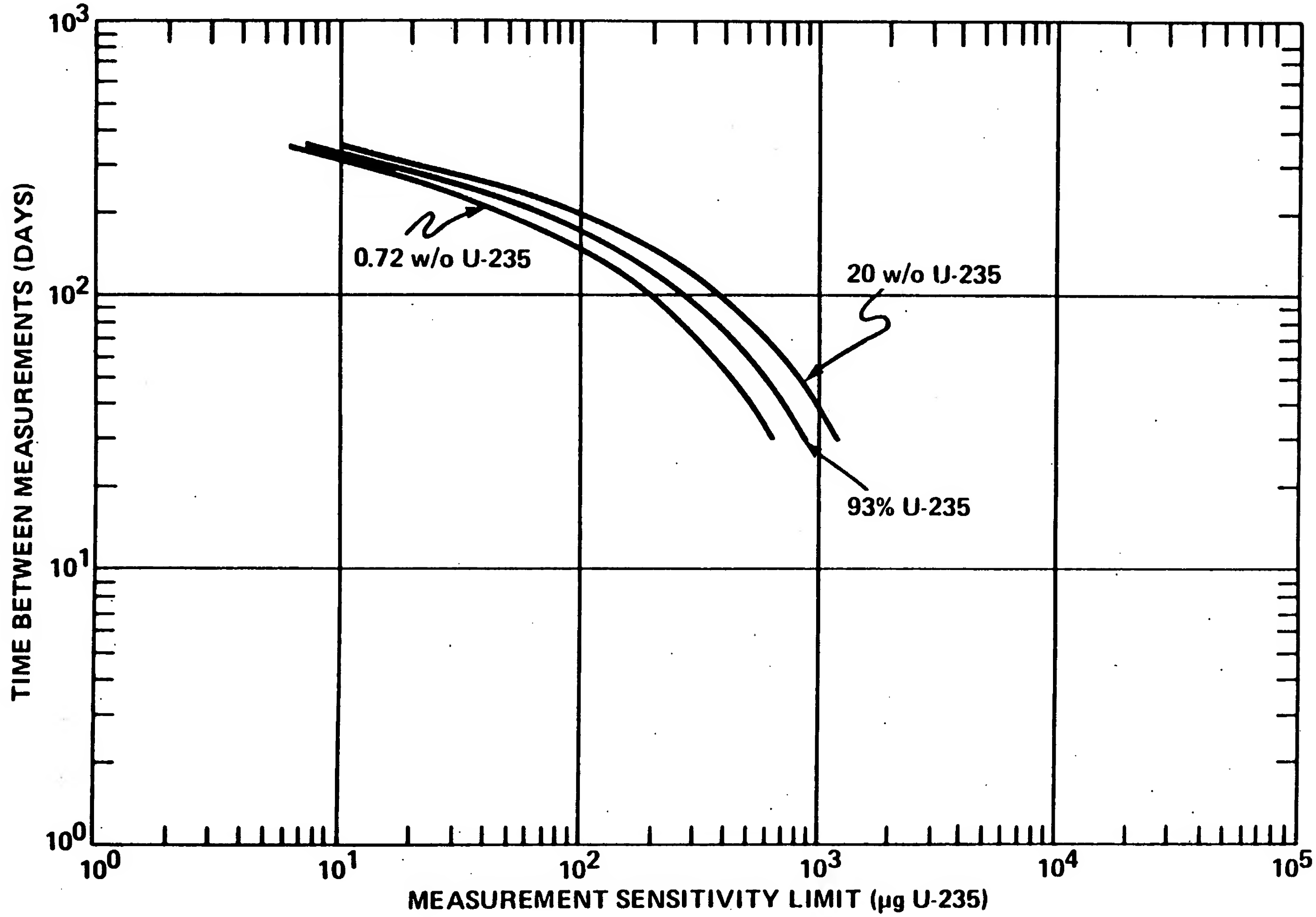


Figure 6 Maximum Time Between Measurements to Detect 1 MPD_c
In Vivo, Class (W)

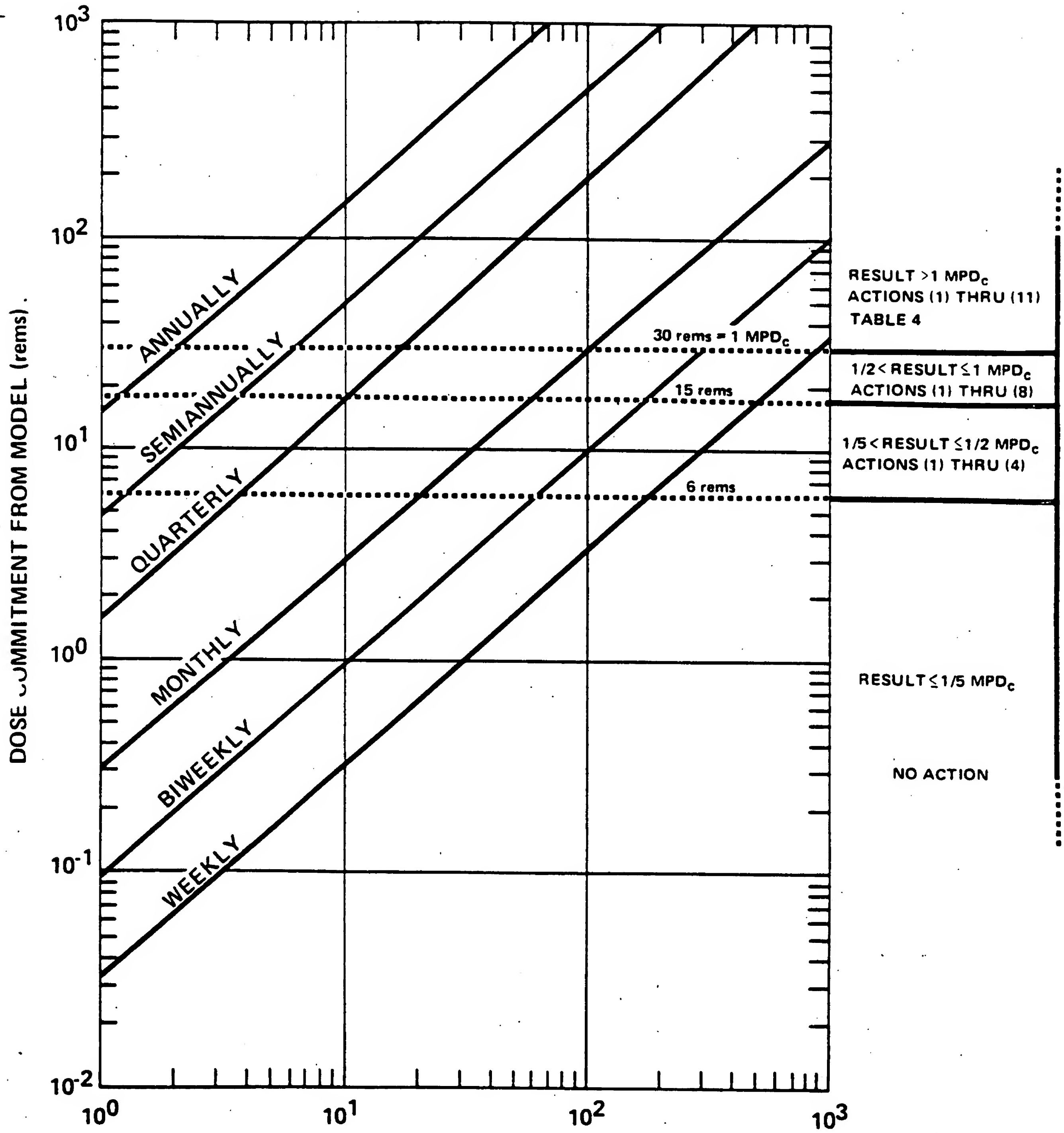


Figure 8 Dose Commitment Indicated by Model vs. Urinary Uranium Concentration, Class (D), Single Intake

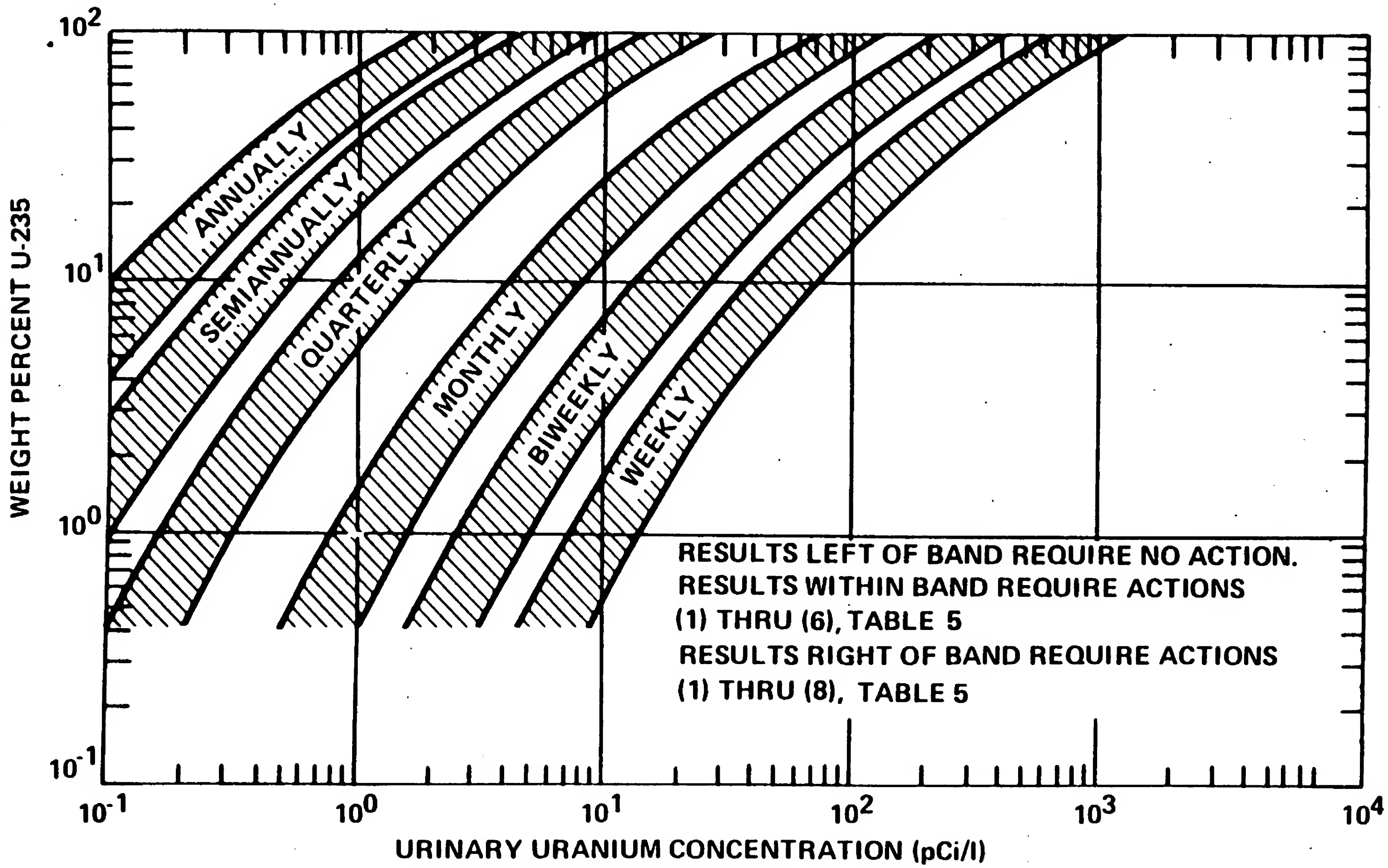


Figure 10 Action Guide for Urinalysis Results Following Single Intake of Uranium, Chemical Toxicity

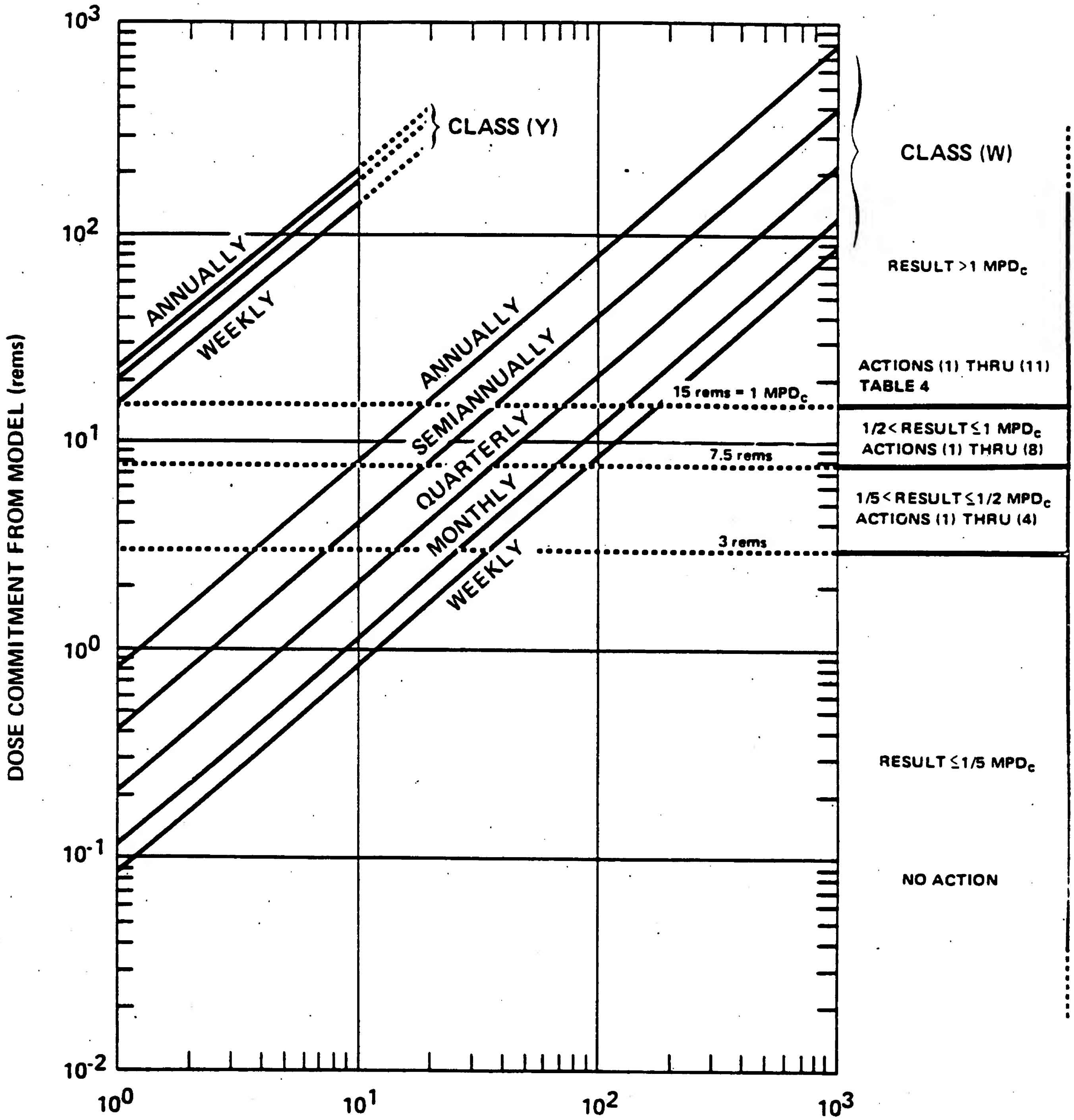


Figure 12 Dose Commitment Indicated by Model vs. Urinary Uranium Concentration, Class (W) and (Y), Single Intake

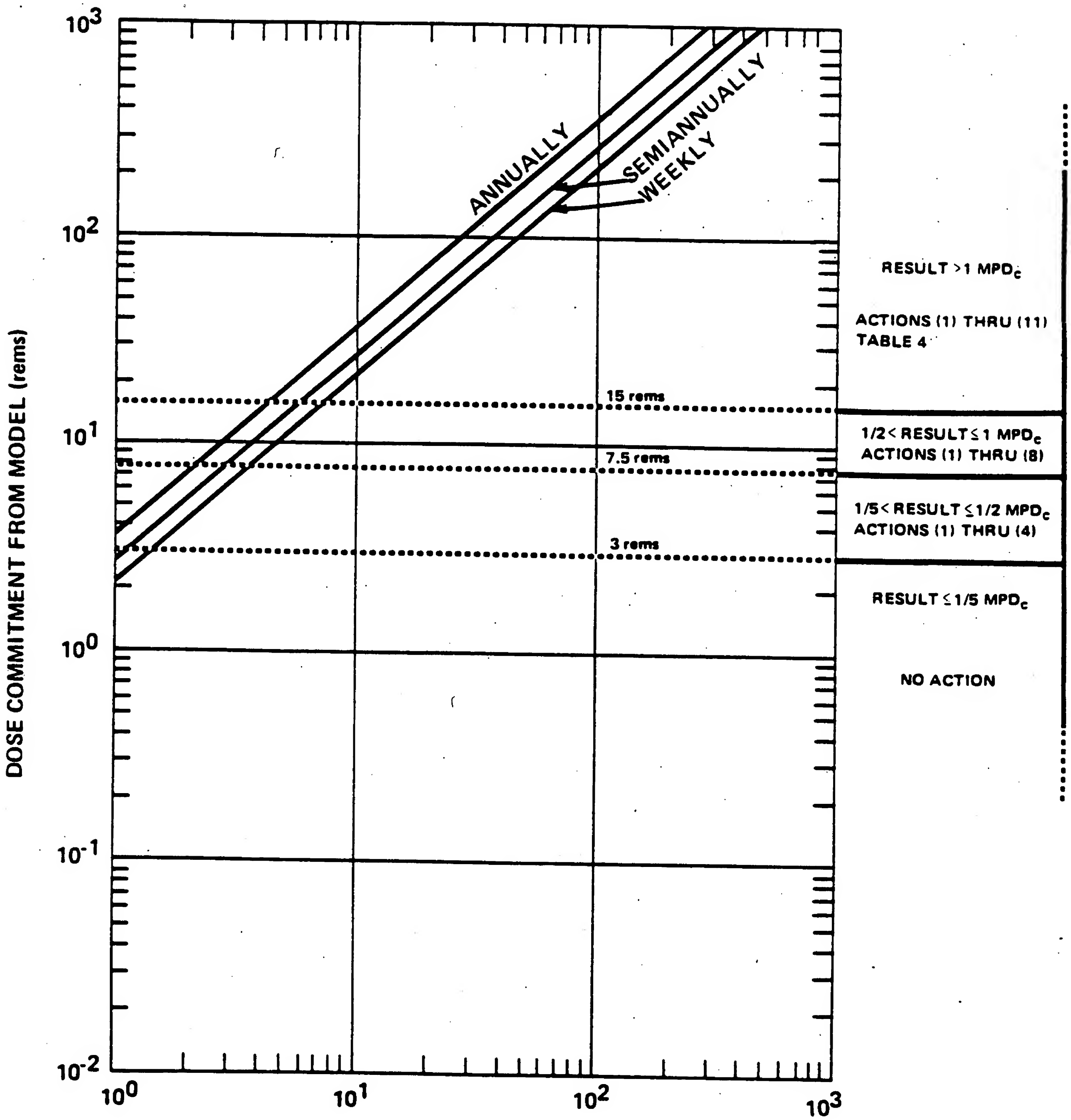


Figure 14 Dose Commitment Indicated by Model vs. Uranium Fecal Excretion Rate, Class (Y), Single Intake

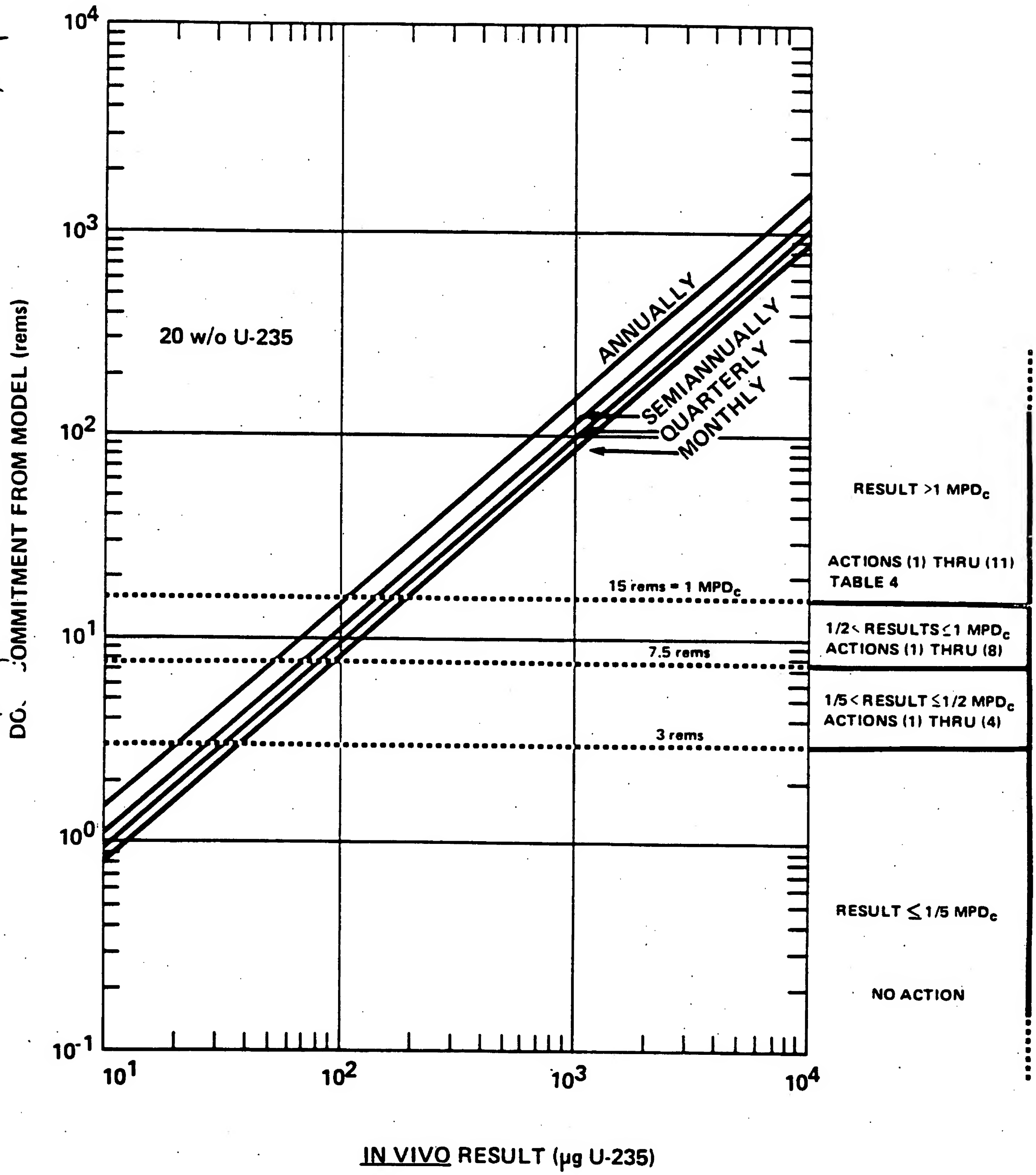


Figure 16 Dose Commitment Indicated by Model vs. In Vivo Result, Class (Y), Single Intake

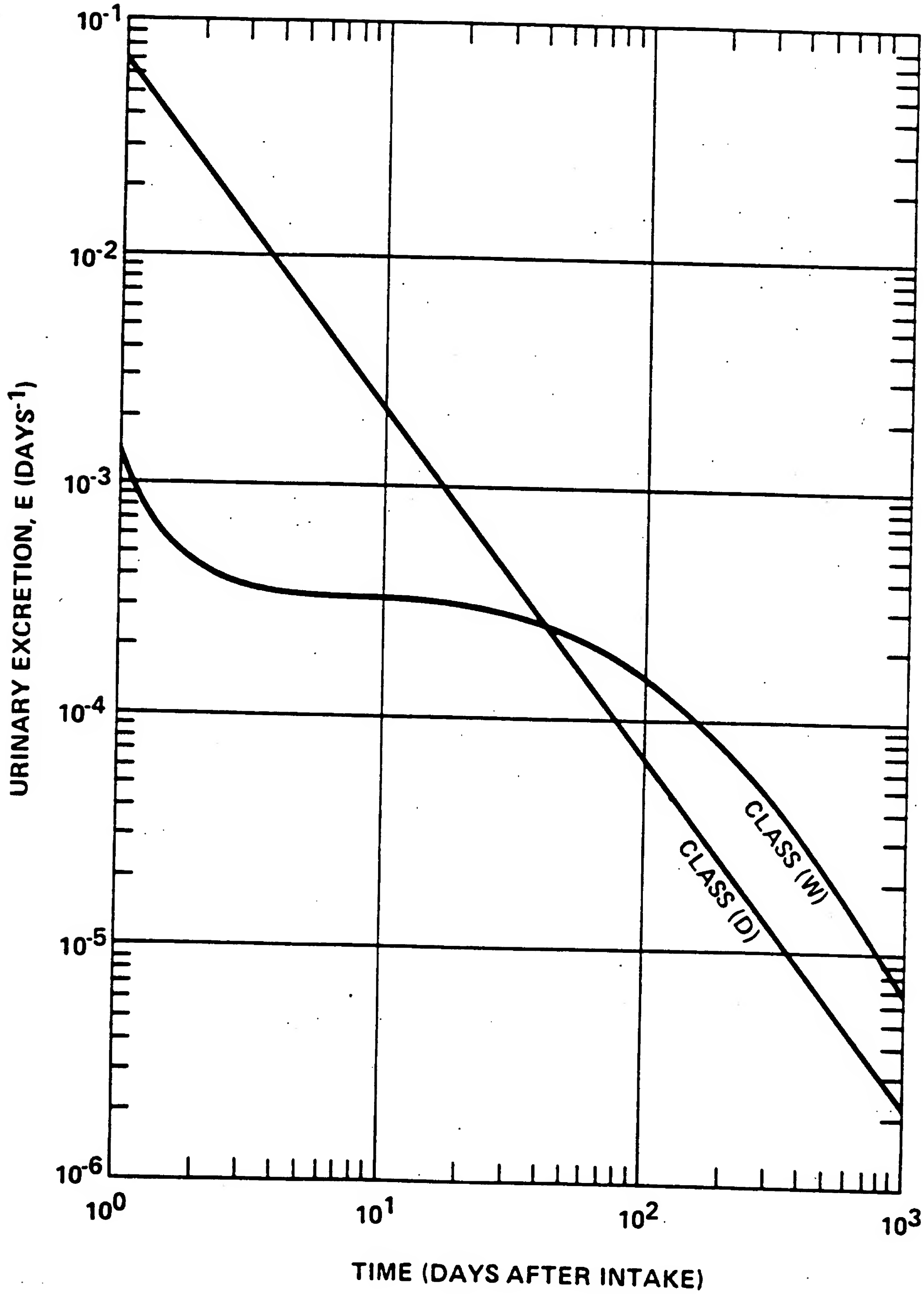


Figure 18 Urinary Uranium Excretion Factors for Determining R_D and R_W

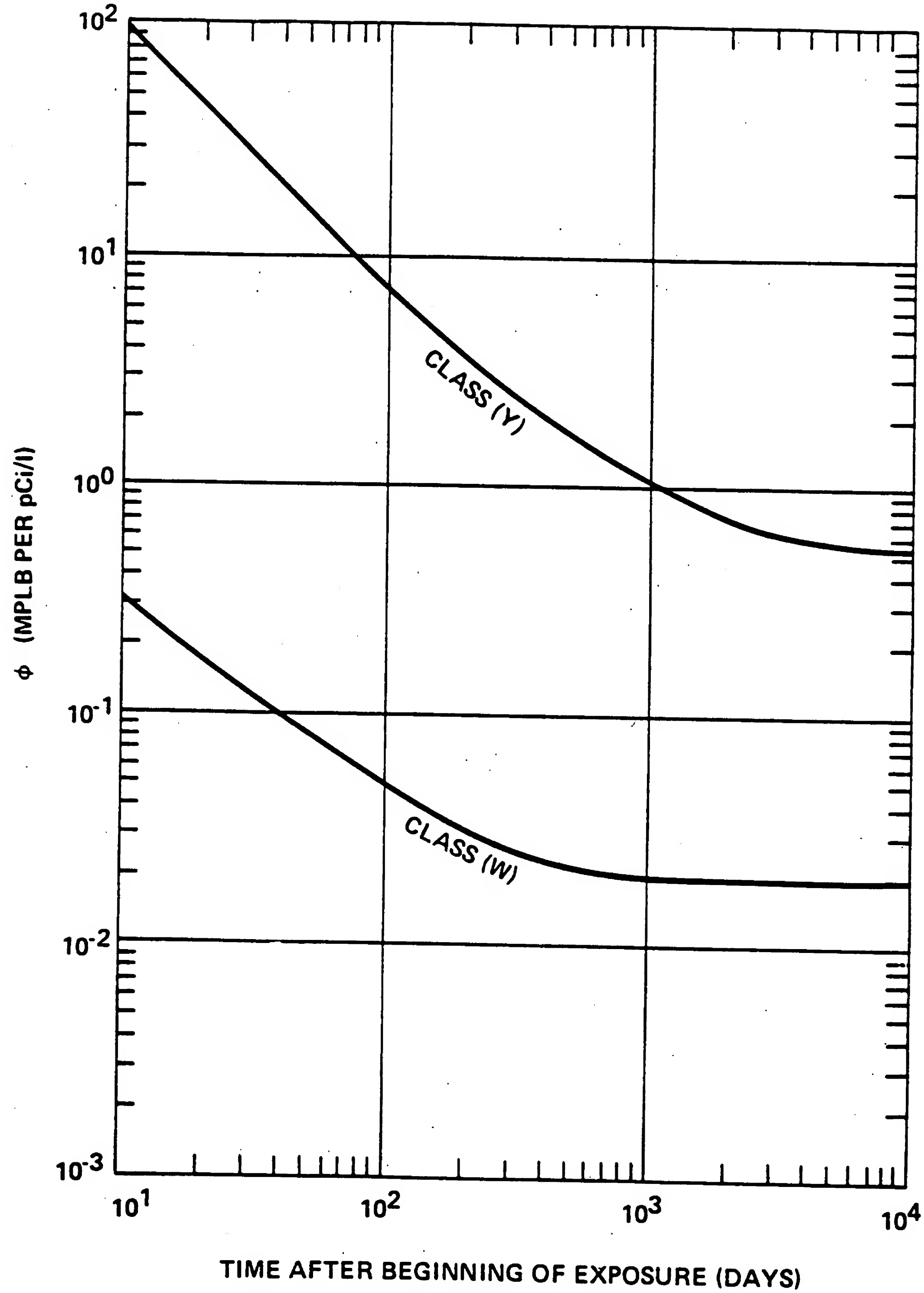


Figure 20 Model for Interpreting Urinalysis Results During Continuous Exposure to Constant Concentration of Uranium in Air

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THE SECRETARY OF DEFENSE

WASHINGTON, THE DISTRICT OF COLUMBIA

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MEMORANDUM FOR THE PRESIDENT

The Memorandum of Understanding with Israel, copy of which I sent to you on the plane yesterday afternoon and another copy which I attach here, fulfills I believe the points you made to me on the telephone Saturday and Sunday in that it does not contain anything which a moderate Arab nation could logically or accurately contend is directed against it.

The agreement is specifically designed for the sole purpose of deterring "all threats from the Soviet Union" to the whole region, and is limited to threats caused by the Soviet Union or "Soviet controlled forces from outside the region introduced into the region." Finally, the agreement provides that "it is not directed at any state or group of states within the region. It is intended solely for defensive purposes against the above mentioned threat." The only military exercises mentioned are "naval and air exercises in the eastern Mediterranean Sea." This does not specifically exclude land forces, but after a considerable negotiating struggle, it also does not specifically identify land exercises, which we were told would have been seized on by the Arab nations as something inevitably directed against them.

The other items in the agreement are mostly procedural and all are limited to activities designed to deter Soviet threats against the whole Middle East.

After some very intense bargaining, the atmosphere was very good, and at both the luncheon and the dinner which we gave for Minister Sharon he seemed pleased, relieved and, to some extent, happy.

As I mentioned, we had dispatched a team to Saudi Arabia to emphasize to Prince Sultan the narrow scope of the agreement, and our Ambassadors in Egypt and Jordan will perform the same function there. Our background press briefing will also emphasize that we have joined up with Israel in this agreement solely for the purpose of deterring Soviet threats against the whole region.

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16 SEP 1997 — DATE

97-F-1646 — CASE #

Classified by Sec Def
Review on 30 Nov 87

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The same agreement will be offered to any moderate Arab state that wishes to sign or enter into oral agreements to the same effect. While it is doubtful that any will accept, it should be further evidence to them that the military security arrangement is not unique nor is it directed against them.

Attachment

cc: Secretary Haig
Ed Meese

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MEMORANDUM OF UNDERSTANDING

BETWEEN

THE GOVERNMENT OF THE UNITED STATES

AND

THE GOVERNMENT OF ISRAEL

ON

STRATEGIC COOPERATION

PREAMBLE

This Memorandum of Understanding reaffirms the common bonds of friendship between the United States and Israel and builds on the mutual security relationship that exists between the two nations. The Parties recognize the need to enhance Strategic Cooperation to deter all threats from the Soviet Union to the region. Noting the long-standing and fruitful cooperation for mutual security that has developed between the two countries, the Parties have decided to establish a framework for continued consultation and cooperation to enhance their national security by deterring such threats to the whole region.

The Parties have reached the following agreements in order to achieve the above aims.

ARTICLE I

United States-Israeli Strategic Cooperation, as set forth in this Memorandum, is designed against the threat to peace and security of the region caused by the Soviet Union or Soviet-controlled forces from outside the region introduced into the region. It has the following broad purposes:

a. To enable the Parties to act cooperatively and in a timely manner to deal with the above mentioned threat.

b. To provide each other with military assistance for operations of their forces in the area that may be required to cope with this threat.

c. The Strategic Cooperation between the Parties is not directed at any State or group of States within the region. It is intended solely for defensive purposes against the above mentioned threat.

ARTICLE II

1. The fields in which Strategic Cooperation will be carried out to prevent the above mentioned threat from endangering the security of the region include:

a. Military cooperation between the Parties, as may be agreed by the Parties.

b. Joint military exercises, including naval and air exercises in the Eastern Mediterranean Sea, as agreed upon by the Parties.

c. Cooperation for the establishment and maintenance of joint readiness activities, as agreed upon by the Parties.

c. Other areas within the basic scope and purpose of this agreement, as may be jointly agreed.

2. Details of activities within these fields of cooperation shall be worked out by the Parties in accordance with the provisions of Article III below. The cooperation will include, as appropriate, planning, preparations, and exercises.

ARTICLE III

1. The Secretary of Defense and the Minister of Defense shall establish a Coordinating Council to further the purposes of this Memorandum:

a. To coordinate and provide guidance to Joint Working Groups;

b. To monitor the implementation of cooperation in the fields agreed upon by the Parties within the scope of this agreement;

c. To hold periodic meetings, in Israel and the United States, for the purposes of discussing and resolving outstanding issues and to further the objectives set forth in this Memorandum. Special meetings can be held at the request of either Party. The Secretary of Defense and Minister of Defense will chair these meetings whenever possible.

2. Joint Working Groups will address the following issues.

a. Military cooperation between the Parties, including joint US-Israeli exercises in the Eastern Mediterranean Sea.

b. Cooperation for the establishment of joint readiness activities including access to maintenance facilities and other infrastructure, consistent with the basic purposes of this agreement.

c. Cooperation in research and development, building on past cooperation in this area.

d. Cooperation in defense trade.

e. Other fields within the basic scope and purpose of this agreement, such as questions of prepositioning, as agreed by the Coordinating Council.

3. The future agenda for the work of the Joint Working Groups, their composition, and procedures for reporting to the Coordinating Council shall be agreed upon by the Parties.

ARTICLE IV

This Memorandum shall enter into force upon exchange of notification that required procedures have been completed by each Party. If either Party considers it necessary to terminate this Memorandum of Understanding, it may do so by notifying the other Party six months in advance of the effective date of termination.

ARTICLE V

Nothing in the Memorandum shall be considered as derogating from previous agreements and understandings between the Parties.

ARTICLE VI

The Parties share the understanding that nothing in this Memorandum is intended to or shall in any way prejudice the rights and obligations which devolve or may devolve upon either government under the Charter of the United Nations or under International Law. The Parties reaffirm their faith in the purposes and principles of the Charter of the United Nations and their aspiration to live in peace with all countries in the region.

For the Government of the United States

Caspar W. Weinberger
Secretary of Defense

For the Government of Israel

Ariel Sharon
Minister of Defense